United States
Department of
Agriculture

Forest Service

**Intermountain
Forest and Range
Experiment Station**

General Technical
Report INT-116

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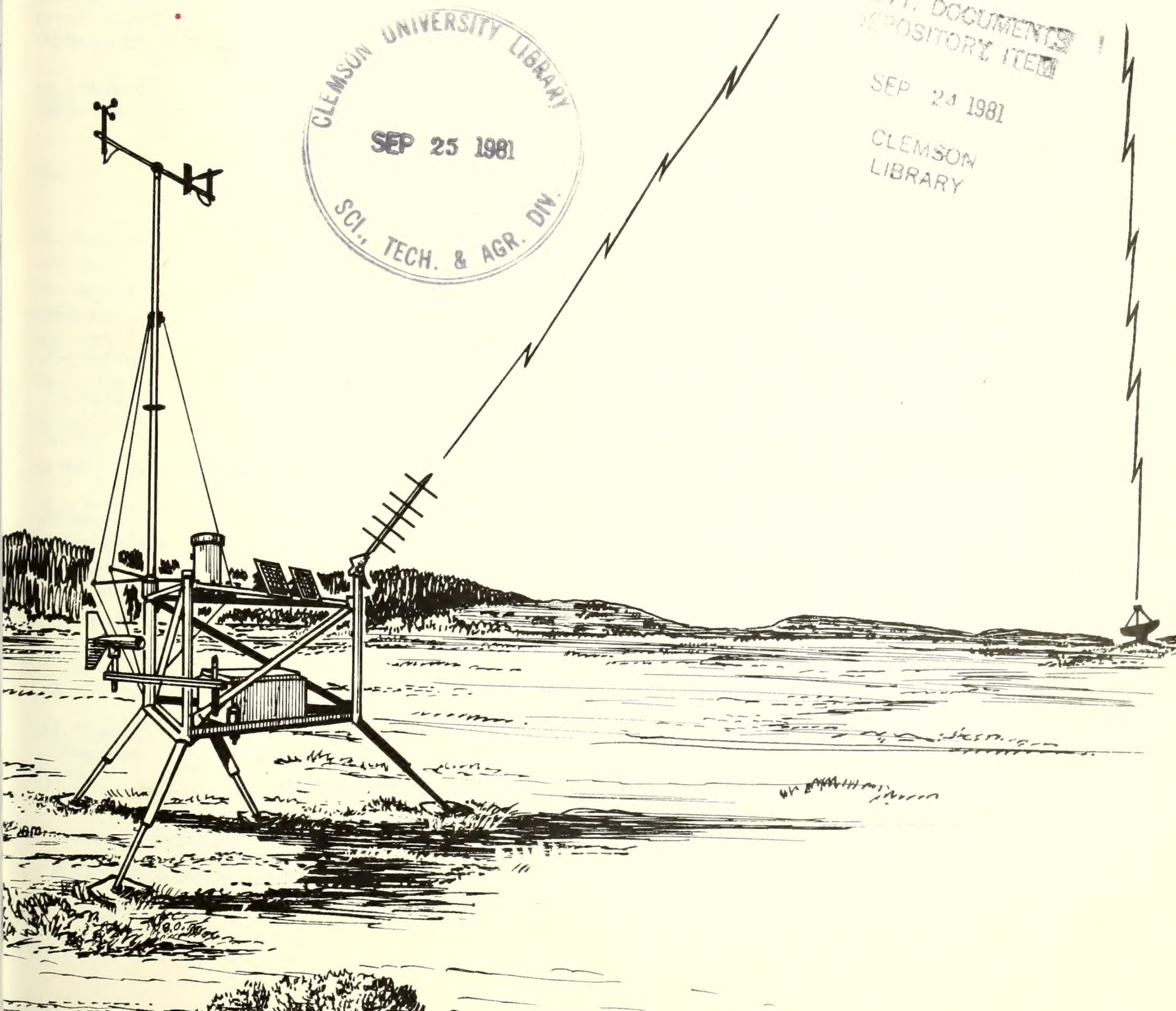
Remote Automatic Weather Station for Resource and Fire Management Agencies

John R. Warren
Dale L. Vance



AUTHORS

JOHN R. WARREN was graduated from the University of Illinois in 1957 with a B.S. in electronic engineering. He has been employed with the Firescope research work unit at the USDA Forest Service Riverside Forest Fire Laboratory in Riverside, Calif. He joined the Northern Forest Fire Laboratory in 1977, stationed in Boise, Idaho. He is currently with the Aviation and Fire Management Staff, responsible for infrared and advanced electronics systems development and testing. He is a registered professional engineer in the State of California.

DALE L. VANCE was graduated from the University of Colorado in 1968 with a B.S. in electronic engineering. He subsequently did graduate work in engineering design and economic evaluation. He joined the U.S. Department of Interior, Bureau of Land Management, Division of Scientific Systems Development, Denver, Colo., in 1974. He is currently working in meteorological instrumentation systems and communications systems and has been instrumental in the development, testing, and deployment of automatic lightning detection systems.

RESEARCH SUMMARY

Remote Automatic Weather Stations (RAWS) have been developed and are now operational across the nation in a variety of geographical areas. RAWS acquire, process, store, and transmit accumulative precipitation, windspeed, wind direction, air temperature, fuel temperature, relative humidity, barometric pressure, and battery voltage. RAWS will operate unattended for 6 months or longer; batteries recharged by solar panels furnish power. Weather data are retransmitted via the Geostationary Operational Environmental Satellite (GOES) to the National Environmental Satellite Service (NESS), Wallops Island, Va., receiving station, and subsequently stored at the World Weather Building in Maryland. Data may be retrieved by direct dial, dedicated phone lines, or through AFFIRMS. Small earth terminals (receiving stations) are also commercially available for direct reception from GOES.

RAWS fulfill a long standing need for automatic weather data acquisition from remote sites. RAWS can be used nationwide as part of the National Fire-Danger Rating System, in clusters over an area of concern, for research, or individually for local weather.

RAWS have been field proven, are operational, and are currently available from two qualified commercial manufacturers.

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INTRODUCTION

RAWS is an acronym for Remote Automatic Weather Station(s). The RAWS discussed in this report were developed over 3 1/2 years by USDA Forest Service (FS) and the U.S. Department of Interior, Bureau of Land Management (BLM) electronics engineers (the authors) and by LaBarge Electronics Division, Tulsa, Okla. The development was a cooperative effort utilizing the experience and knowledge of the engineers involved and a complete sharing of development, test, and operational results. Through this cooperative, interagency approach, duplicative, redundant efforts and costs were avoided. Cost savings and commonality of stations, data, and spares have been achieved.

The RAWS are remote. They may be installed in essentially any geographic region or climate and in any terrain. The only restrictions are that there must be line of sight from the antenna to the Geostationary Operational Environmental Satellite (GOES), and there must be enough sunlight to maintain the battery charge via the solar panels.

The RAWS are automatic. Once installed and activated, they automatically acquire, process, and store local weather data for subsequent transmission. No personal attention, access, or instrument readings are required.

The RAWS are weather stations. The RAWS acquire, process, store, and transmit the following data:

- accumulative precipitation-rain gage (RG)
- wind direction (10 minutes filtered or average) (WD)
- windspeed (10 minutes filtered or average) (WS)
- air temperature (AT)
- fuel temperature (FT)
- relative humidity (RH)
- battery voltage (BV)
- barometric pressure (BP)

The barometric pressure is currently monitored on BLM stations only. A blank data address is used on FS stations to retain commonality of data format. There is also capability to add other weather measurements in the future by adding the instrument, cabling, and signal conditioning circuitry.

The RAWS stand alone. No commercial power or telephone connections are used. The stations can be installed and activated in approximately 3 hours by two experienced technicians. RAWS do not require repeater stations or local base/master stations. The only repeating link is via the GOES, which is part of the total National Environmental Satellite Service (NESS) data collection system (DCS). Figures 1 and 2 are pictures of the first installed RAWS. Figure 3 is a schematic representation of RAWS.

Figure 1.--*Installation of the first RAWS unit required 2-1/2 hours. The 20-foot sensor mast can be easily pivoted upward for installation and downward for easy access to windspeed and wind direction sensors.*

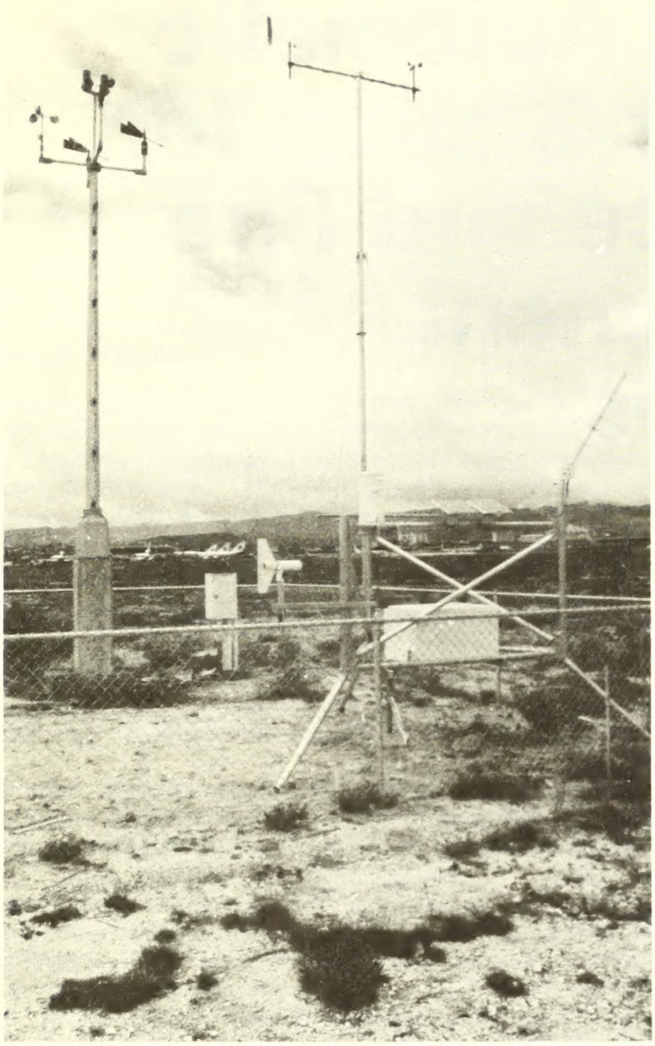


Figure 2.--*The solar-powered RAWS unit installed at the Honolulu International Airport. RAWS meteorological data were compared to those of a nearby NWS monitoring site.*

BACKGROUND

The small weather stations used by the Forest Service and BLM have traditionally been located outside ranger stations or similar offices. Once or twice a day someone dutifully treks to the station, observes and records instrument readings, and telephones or radios the data to some central or sub-central recording office. The data may then be entered, through a suitable terminal, into the Administrative Forest Fire Information Retrieval and Management System (AFFIRMS) computer system. AFFIRMS then calculates the localized fire danger rating, based on those and other data, in accordance with the National Fire-Danger Rating System (NFDRS) methods. Land managers can then plan the next day's activities, such as fire crew positioning, prescribed burn actions, etc., for their area of responsibility, from the fire danger potential and other considerations.

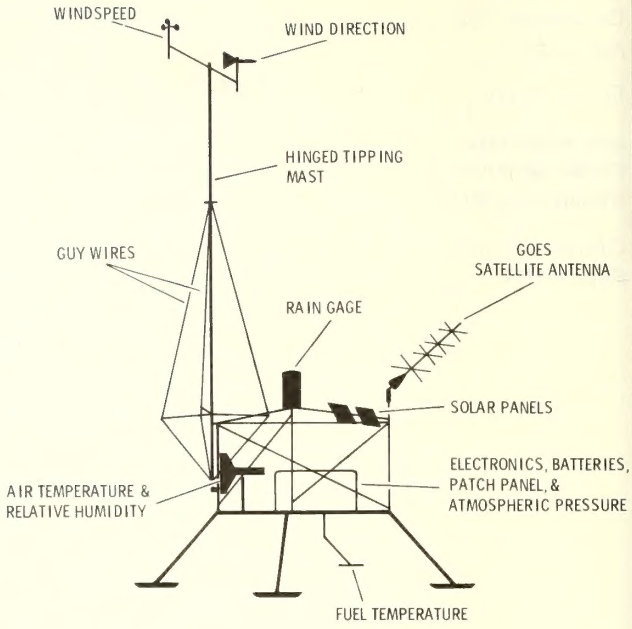


Figure 3.--*Schematic representation of RAWS.*

Unfortunately, the weather at a ranger station is not always correlative with or even indicative of weather on top of a mountain, over the hills, or in other pertinent areas. Accessibility, cost of personnel and transportation, and time differences in readings have essentially precluded the use of nonautomatic stations for securing weather data in remote locations. Further, during fires or other abnormal situations, people are not always available, even at ranger stations, to read the instruments and report the weather--when it is most urgently needed.

Stations (other than the GOES-based RAWS) that could be designed for remote automatic operation include telephone links, VHF or other radio systems, and meteor-burst systems. The cost of telephone line installation to most remote sites would eliminate their consideration. Reliability of phone lines, especially during fires when poles may be burned down, would also raise considerable doubts regarding their suitability. The esthetic value of scenic areas may also be adversely affected by poles and lines.

Radio link systems at VHF or higher bands require line of sight from the remote station to the base station or to a repeater, which in turn needs line of sight to the base. This restricts locations of remote sites and/or imposes the complexities of multiple repeater hops. Electromagnetic interference can be a difficult problem, especially at choice repeater sites that may already be loaded with repeaters and remote transmitters. Frequency allocation approval is another significant hurdle since frequency spectrum usage is stretched to capacity. Radio link systems also become clusters of systems, of perhaps 4 to 8 remote stations, a few repeaters and a base station. The clusters then require a person at the base station to gather the relayed data and send it to another center for entry into AFFIRMS. In very remote locations, such as interior Alaska, the radio system would be questionable in both performance and cost.

Meteor-burst communications systems utilize the ionized trails of meteors to effectively "bounce" radio frequency transmissions over great distances (up to 500 miles [804 km] or so). The usable time of an ionized trail is short, but it is often sufficient to establish a two-way path with a duration adequate for data bursts that could contain weather data. Experimentation has arrived at the statistical probabilities of success, number of interrogations, etc., for various parts of the western United States and Alaska at different times of the year. A meteor-burst system is in use for snow measurements. At the time of selection of the RAWS-GOES, the meteor-burst system was not operational; planned snow measurement sites were not compatible with fire weather sites; the remote stations were larger (some requiring commercial power); and there were no cost or performance advantages. Operation was also limited to the western United States and Alaska.

In 1975 the FS began investigating the use of data collection platforms (DCP's) working in conjunction with the GOES as a means for automatically gathering weather data from remote sites. (The DCP contains the data collection/storage/transmission electronics for the RAWS.) A data collection platform using GOES was being developed by LaBarge Electronics for the U.S. Geological Survey (USGS) for automatic transmission of water levels in rivers, reservoirs, and lakes. Technical discussions were held with LaBarge engineers on DCP design and adaptability to weather station use. Discussions and facility tours were made with NESS at the World Weather Building (WWB) data processing system and the Wallops Island, Va., command and data acquisition station. The FS and BLM engineers had initiated the coordination process. It had also been determined that a GOES-based RAWS would not have the disadvantages of the other types of stations.

RAWS went through three iterations to arrive at its present configuration: experimental, prototype, and field evaluation (now operational) configurations. Figure 4 shows the prototype configuration. In 1976 the FS set up and operated two experimental RAWS using basic weather instruments. (A later version using selected weather instruments and new signal conditioning was operated for a short time in 1977.) In 1977, the BLM set up and operated two prototype RAWS, procured as entire stations from LaBarge. In 1978, FS and BLM engineers, working with LaBarge engineers, developed requirements for 10 field evaluation units. The field evaluation units were based on experience with the experimental and prototype stations and represented the consolidated and coordinated recommendations of the authors. The stations also met the data requirements of the RAWS Steering Committee and the NFDRS Implementation Team, established in January 1978.

RAWS DESCRIPTION AND OPERATION

The RAWS consist of seven primary parts: (1) tower asembly, (2) sensors, (3) signal conditioning unit (SCU), (4) sensor interface assembly, (5) convertible data collection platform (CDCP), (6) antenna, and (7) power source.

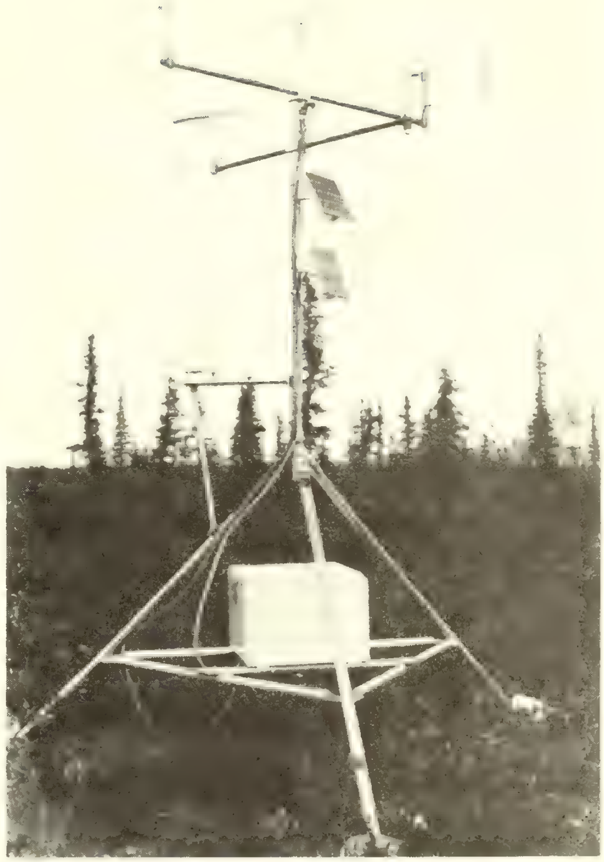


Figure 4.--*Prototype configuration of the RAWS unit.*

1. **Tower assembly**.--The tower assembly consists of the basic structure, a mast, guy wires, cable raceways, and the electronic enclosure. The basic structure is a triangular, prism-shaped tripod supported on tundra pads. Each of the three legs is adjustable in 1-inch increments, from 1 inch to 16 inches (2.54 cm to 40.6 cm) to allow for tower leveling. All horizontal members, all diagonal members, and all tundra pads are interchangeable. The vertical members of the triangular prism structure form into part of the legs and may be positioned in any of the three corners, depending upon the desired location. The basic structure is designed from 2-inch and 2.25-inch (5.08-cm and 5.72-cm) aluminum pipe for strength and light weight.

The two-piece, detachable mast extends 20 ft (6.1 m) above the ground plane when the adjustable feet are in their center position. The mast is hollow (2-inch [5.08-cm] aluminum pipe) to conceal and protect the sensor cables coming from the top of the mast and is lightweight for ease of handling. The mast is designed to be lowered away from the tower by removing one bolt and "walking" it away from the basic structure as it pivots on its lowest point of connection, thus allowing direct access to the sensors mounted at the top of the mast. An aircraft-type support cable is permanently attached to the mast from the vertical member of the basic structure to hold the mast in a horizontal position 4 ft (1.22 m) above the ground while it is in the lowered position. This permits safe

and ready access to the wind instruments for installation and trouble shooting. It is an innovative, marked improvement from the need to climb towers at the risk of life, limb, and wind instruments. The tower is stable and designed to withstand wind loads of 100 mi/h (161 km/h).

The guy wire assembly braces the mast, especially during the high winds. The guy wires are designed to be an integral part of the mast, so they do not require removal during the raising or lowering of the mast and are spaced at 120-degree angles from each other. The lower ends attach just above the lower pivot point of the mast while the upper ends attach about 6 ft (1.8 m) below the top of the mast. Each wire has a turnbuckle for tightening or loosening the wire and a wingnut to lock the turnbuckle after adjustment. The guy wires are aircraft-type cables specifically designed for high-tension applications.

The cable raceway holds and protects the sensor cables routed from each sensor to the tower enclosure. The raceways are attached to the tower by pipe clamps that are readily removed or installed. Each raceway has a snap-on cover for fast removal or installation.

The tower enclosure is a NEMA-type enclosure attached to the tower by a UNISTRUT platform. The enclosure, after installation, contains the CDCP, SCU, barometric pressure sensor, SCU/interface chassis, and two batteries. The enclosure is vented to prevent moisture buildup and is accessible by standing inside the basic tower structure.

2. **Sensors**.--There are seven standard sensors in the remote meteorological station:

a. **Precipitation sensor**.--The precipitation sensor measures precipitation in the form of rain. An 8-inch (20.3-cm) diameter orifice collects the water, which is directed through a funnel to a tipping bucket mechanism. A mercury switch closes each time the bucket tips, thereby providing a momentary switch closure. The tipping bucket mechanism consists of two small containers positioned to collect the precipitation as it drains through the funnel. When 0.01 inch (0.025 cm) of precipitation has been collected, the bucket tips, draining the collected water out the bottom of the gage and positioning the second bucket to begin collecting precipitation.

b. **Windspeed sensor**.--The windspeed sensor is a 3-cup anemometer designed to have a low velocity threshold. The metal cup assembly includes a permanent magnet that operates a sealed magnetic reed switch on the nonrotating part of the assembly. As the cup assembly rotates, it closes the reed switch, providing switch closures to the windspeed translator module. The frequency of the switch closures is proportional to the windspeed. The anemometer is mounted on the crossarm at the top of the 20-ft (6.1-m) mast and interfaces with the windspeed translator module through the signal cable.

c. **Wind direction sensor**.--The wind direction sensor is a lightweight airfoil metal vane. The vane is coupled to a precision microtorque potentiometer for low-threshold operation. Output of the wire-wound potentiometer varies proportionally with wind direction. This output is produced as the wind direction module applies a precise voltage to the potentiometer and the potentiometer output becomes a voltage proportional to the wind direction. The wind direction vane is mounted on the crossarm at the top of the 20-ft (6.1-m) mast and interfaces with the wind direction module through the signal cable.

d. **Air temperature sensor**.--The air temperature sensor is a solid-state linear thermistor and precision resistor network, potted in a shockproof 3/8-inch (0.95-cm) (outside diameter) stainless steel housing. The sensor is positioned in a vane-aspirated radiation shield to reduce the effects of solar radiation upon the temperature data. The air temperature is sensed with a linear three-element thermistor. The output of the sensor is a resistance proportional to the ambient temperature. The air temperature sensor is positioned 4 to 5 ft (1.2 to 1.5 m) from the ground surface and is coupled to the air temperature module through the air temperature cable.

e. **Fuel temperature sensor**.--The fuel temperature sensor is a solid-state linear thermistor and precision resistor network potted in a 6-inch x 3/8-inch (8.5-cm x 0.95-cm) dowel stick. The stick is mounted on an adjustable arm positioned approximately 10 inches (25.4 cm) above the ground plane. The arm is positioned on the south side of the tower to insure that the stick is in direct sunlight. The sensor stick is attached to the arm with cable clamps that support the sensor stick as well as insulate it from the metal arm. The temperature of the stick is sensed with the linear three-element thermistor. The output of the sensor, a resistance proportional to the temperature of the fuel stick, is coupled to the fuel temperature module through the fuel temperature cable.

f. **Relative humidity sensor**.--The relative humidity sensor is a polymer, thin-film capacitor contained in the air temperature sensor housing for protection. The sensor is also protected by a 216 micron sintered bronze filter. The thin-film capacitor is composed of an upper and lower electrode with an organic polymer dielectric about 1 micron thick. Water vapor is absorbed into the polymer after the vapors pass through the upper metal electrode. The result is that the capacitance changes linearly as the moisture increases or decreases. The sensor output is coupled to the relative humidity module through the relative humidity cable. The relative humidity sensor is positioned on a cross-arm approximately 4 ft (1.2 m) above the ground plane.

g. **Barometric pressure sensor**.--The barometric pressure sensor is a sensitive aneroid barometer that provides a resistance output proportional to the barometric pressure. It utilizes an evacuated bellows that is sensitive to changes in absolute pressure and is mechanically connected to the arm of the potentiometer. The barometric pressure sensor is housed inside a weather-proof enclosure to protect the sensor. For the RAWS application, the complete barometric pressure assembly is mounted inside the tower enclosure.

3. **Signal conditioning unit (SCU)**.--The signal conditioning unit is the housing for the sensor signal conditioning modules. Each of the sensors has a signal conditioning card in this unit. Each sensor module is plugged into the card rack, which contains card-edge connectors that interface input/output functions to each of the modules. Besides the sensor modules, the SCU also contains a battery monitor module that supplies analog data proportional to the system battery voltage. All sensor modules, except precipitation, provide outputs scaled from 0-5 volts analog over the dynamic range of the sensor. The precipitation module stores the number

of times the tipping bucket has tipped, hence, the measure of total rainfall. The precipitation module counter circuit can be cleared to all zeros by the accumulator display.

4. **Sensor interface assembly**.--The sensor interface assembly is comprised of the sensor cables and the sensor/SCU interface chassis. The cables are cut to length so that there are not excessive cables to store. Each cable is marked with its sensor name (example - WINDSPEED) for fast identification. The cables are vinyl coated to provide protection from the environment.

The cables are interfaced to the SCU through the interface chassis, which provides a junction point for all sensor cables. The chassis is clearly marked to identify each sensor cable mating connector. The sensor interface chassis is mounted on the enclosure wall for easy access and visibility.

5. **Convertible data collection platform (CDCP)**.--The CDCP is a completely microprocessor-controlled data acquisition system. It accepts the sensor data at the specified programed times, converts it from analog to digital (if it is analog), or accepts it directly if it is digital, and stores the digitized data in memory for subsequent retrieval and data transmission. For RAWS application the CDCP is programed to receive and process the sensor data each hour and to transmit the stored data every 3 hours. Therefore, each data transmission will contain three data samples from each sensor.

The CDCP is designed to go into a lower power, minimum operation mode during the time when data are not being acquired, processed, or transmitted. The low-power mode draws an insignificant amount of current compared to the charging rate of the batteries.

The CDCP controls the application of power to all sensors except the windspeed, wind direction, and precipitation sensors, which remain powered up continuously. The CDCP is connected to the SCU with the SCU/CDCP cable. The CDCP is positioned in the tower enclosure.

6. **Antenna**.--The antenna is specifically designed for transmitting to the GOES satellite. It consists of two quadrature-phased cross-element yagi antennas mounted on a common boom. The antenna is mounted on the tower on the extended vertical section of the basic structure and connects to the CDCP through the antenna cable. The position does not interfere with airflow to the wind sensors.

7. **Power source**.--The power source consists of two gel-cell batteries connected in parallel and charged by two solar panels with regulators. The solar panels are positioned on a horizontal member of the basic tower. The horizontal member is positioned so that the panels receive direct sunlight and are not shaded by any object on the tower. Sealed 12V automotive batteries have also been used successfully in some installations.

Support equipment.--The support accessories for the RAWS include the CDCP test set and the tipping bucket accumulator display. These items are not a permanent part of the RAWS but are required in setting up and maintaining the station.

The test set is used to activate, time, enter constants into the CDCP, and to read the data as stored in the CDCP memory. The test set is essential for troubleshooting and also for manipulating the CDCP and its memory to utilize the flexibility of the system.

The tipping bucket accumulator display is used to simulate the precipitation sensor, to monitor the precipitation module in the SCU, and to reset or clear the counter circuit on the precipitation module.

The DCP contains the "brains" for the RAWS. The microprocessor controls power, timing, input, storage, and output. One must be fluent in analog, digital, binary, hexadecimal, ASCII, RF, logic, power, modulation, and instrumentation circuits/codes to fully understand RAWS operation.

The activation sequence requires setting the timing precisely using WWV reference, entering station ID and operation mode constants into memory, entering constants unique to the particular setup, and adjusting the data buffer pointer to the desired position.

GOES DESCRIPTION AND OPERATION

The GOES-DCS system is shown in figure 5. The GOES and the geostationary orbit are shown in figure 6. Note that the GOES accomplishes many functions in addition to the data relay from DCP's.

A summary of DCP characteristics is provided in appendix 1.

Data are acquired in analog (except for digital measurements), converted to digital, and stored in binary form in DCP memory. The test set converses with the DCP and test set user in hexadecimal. Just prior to transmission, the non-return-to-zero (NRZ) binary data are converted to Manchester coding for transmission. The 401.XXX MHz transmitter is biphase shift keyed ±60 degrees from the nominal carrier phase reference to correspond to the one or zero Manchester level of the data. Following an unmodulated carrier transmission, some specially coded housekeeping sequences and station ID, the data bits are transmitted at 100 bits per second to the GOES.

In normal FS/BLM operation, the RAWS are programed and set up to acquire and store data every hour and transmit every 3 hours. The microprocessor will follow this approximate sequence of events: every 15 minutes add 1 count to the data acquisition and transmit interval counters. If the data acquisiton count matches the programed count (4 for 1 hour), power up the sensors (except those on continuous power), sample the outputs, and store the new data in memory, replacing the oldest data. If the data transmit interval count matches the programed count (C or 12 for 3 hours), three hourly data sets will be transmitted following the data update. After completion of the actions required and updating counters and pointers, the microprocessor puts the station back into a low-power drain, semisomnus mode, and waits for the next 15 minutes to pass.

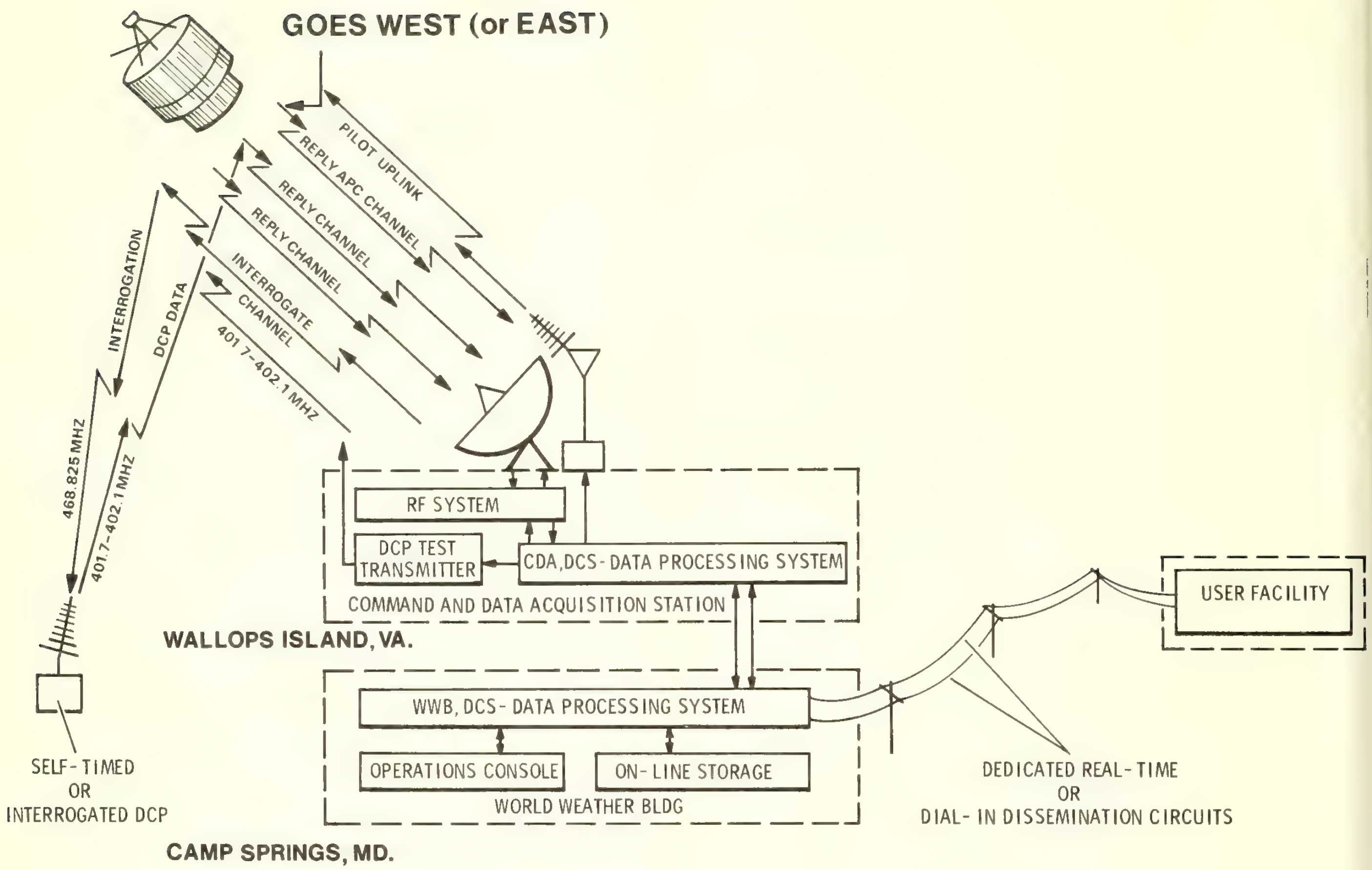


Figure 5.--*GOES/DCS system description.*

The GOES-DCS is a synchronous satellite based communications system for collecting geophysical data from virtually any point on the Western Hemisphere. Although this system description is concerned only with the DCS portion of the GOES system, the spacecraft (S/C) and the Command and Data Acquisition Station (CDA) have several missions. The GOES system provides the following functions:

1. The VISSR system has a visible and infrared spin-scan radiometer that views the earth's cloud cover and surface and transmits the data to earth.

2. The stretched VISSR system transmits processed VISSR data to data utilization stations via the GOES satellite.

3. The WEFAX system transmits weather facsimile cloud cover pictures to users via the GOES satellite. (Seen on TV weather forecasts.)

4. The SEM system monitors the space environment and transmits particle energy and trajectory data to the Boulder, Colo., Space Disturbance Forecast Center.

5. The DCS system relays data from both self-timed and interrogated DCPRS units to the CDA. The DCPRS units interface with ships, buoys, rain gages, river level gages, seismographs, remote weather stations, etc.

6. The CDA command and telemetry system enables the CDA to configure the satellite and monitor its status.

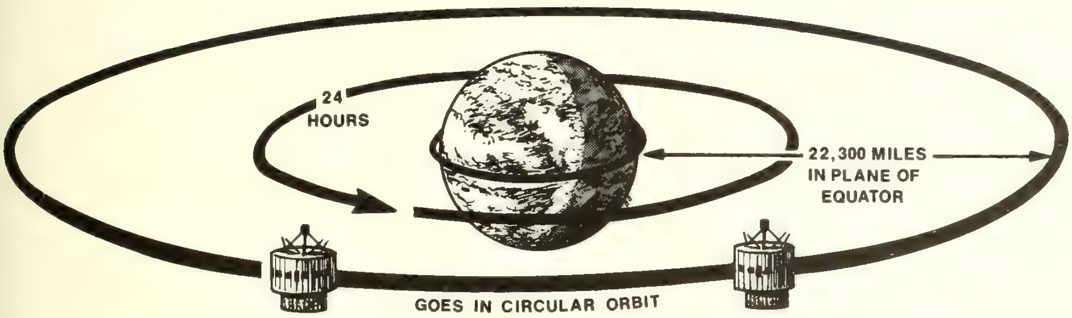
A complete communications link from a set of remote sensors to a user employing the GOES/DCS normally will consist of the following elements:

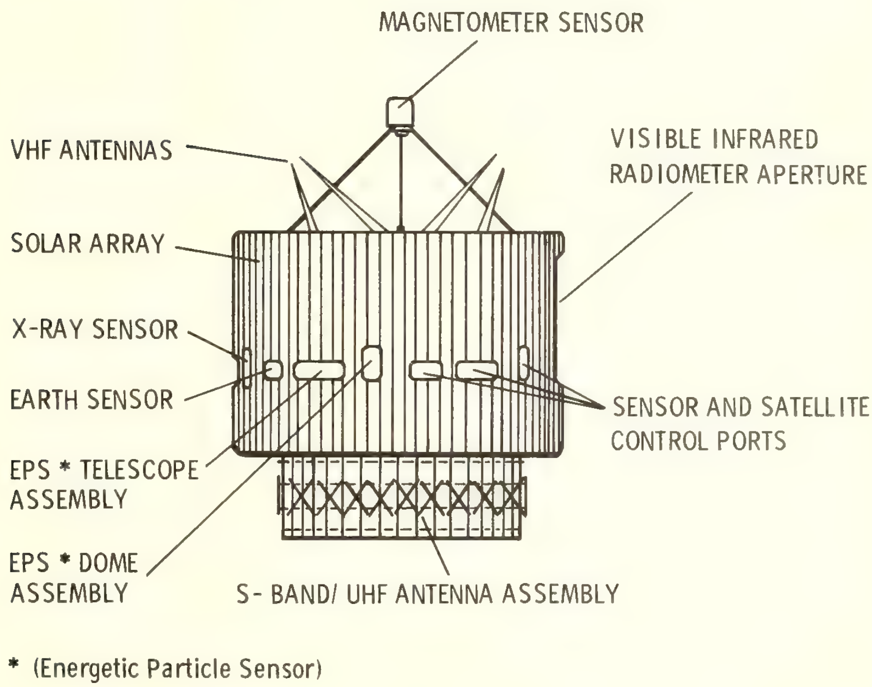
1. A DCP--this unit converts sensor data to a 100 bit/second, Manchester-encoded serial data stream, phase modulated on a UHF (402 MHz) carrier at an EIRP of approximately ±50 dBm.

2. A UHF to S Band transponder in synchronous earth orbit--this subsystem of the GOES S/C receives the DCPRS signal, up converts it to 1694 MHz, and retransmits the signal to an earth receiving system.

3. The CDA station--this is the GOES earth station located at Wallops Island, Va. Signals relayed through the S/C are received by a large parabolic antenna, amplified, down converted, demodulated, and multiplexed together with nine other DCPRS channels. A 16 bit mini-computer receives and formats the data for transmission over dedicated, conditioned, leased land lines to the DCS/DPS.

4. The DCS/DPS--this is a large scale computer system in the World Weather Building, Camp Springs, Md. (NESS offices), which receives all DCPRS data from the CDA. The DCS/DPS carries out the multiple functions of





igure 6.--*Geostationary (or synchronous) orbit.*

scheduling all activity within the DCS, checking data for errors, disseminating the data, maintaining performance histories on individual DCPRS units, and routinely testing the system for failure identification. Users may communicate with the DCS/DPS over either dedicated realtime land ines or via one of the two dial-in (user demand) circuits operating at 300 or 1200 baud.

5. A data terminal--this is the final hardware element required to complete the normal communications link from a DCPRS. The terminal can be as simple as an ASR-33 teletype or as complex as a postprocessing computer system, depending on the volume of data and processing requirements.

EVALUATION

RAWS sites were selected in various States to cover a wide range of climate and geography. The States were selected by Cooperative Fire Protection (CFP), State and Private Forestry (S&PF) of the Forest Service, with cooperative agreements to cover the subsequent operation and maintenance of the stations. The RAWS were placed in Honolulu, Hawaii; Plains, Mont.; Hill City, Minn.; London, N.H.; and Tallahassee, Fla. All were located near or adjacent to an existing manual station. The five stations were set up and activated during June 1978, with a planned evaluation period running to about October 1, 1978. Data from the RAWS were compared with data from the manual stations during that time. The data were retrieved from the NESS computer via dial-up lines at the site location and at the Boise Interagency Fire Center (BIFC).

RAWS sites were selected in Alaska on the basis of the need for data from particular remote areas. Fire Management Alaska utilized information from a previous climate study, National Weather Service, and a knowledge of the fire problem areas in reaching their location decisions. Elevation was an important factor in station placement. Before RAWS, meteorological data were usually obtained at locations where BLM had fire operations. The fire bases were usually located at low elevation and frequently near water. With freedom to pick an ideal location, RAWS sites were set up at increased elevation in representative fire fuels, away from water.

The Alaska sites selected were:

Sites	Latitude	Longitude	Elevation	
			Feet	*Meters*
Jade Mountain (JDM)	67°30'	158°00'	500	152
Wein Lake (WNL)	67°30'	150°45'	690	210
Salmon Trout (SMT)	67°00'	141°10'	1800	549
Kiwalik (KWL)	65°25'	162°10'	700	213
Innoko (NKO)	63°25'	158°50'	210	64

During installation of the 10 evaluation stations, several problems were encountered and resolved. Following initial installation, three sensors and one DCP failed during the evaluation period. (The evaluation period was June to October, comparable to a "normal" fire season.) Based on the small evaluation sample of 10 stations, this would indicate a return trip to 40 percent of the stations over a season.

The five stations situated adjacent to manual stations met tolerances for all measurements except relative humidity (RH). The RH readings from RAWS were consistently lower than those from the manual stations. The RH sensor has since been incorporated into the air-aspirated air temperature sensor housing and calibration procedures have been improved. (This modification appears to have resolved the problem, but it is still being watched.) The evaluation concluded that RAWS are reliable and can be considered operational. (The 10 evaluation units are presently being used as operational units.) A detailed report of the evaluation is available.[1]

Subsequent to the 10-station evaluation, 10 more stations were procured (five by FS and five by BLM) and are in operational use. These stations have operated satisfactorily and confirm the initial evaluation conclusions of reliability and operational readiness.

The evaluation and operational stations have also provided opportunity to evaluate field maintenance needs and technician capabilities. It appears that a competent radio or electronics technician who accompanies experienced RAWS technicians during a RAWS installation and activation can subsequently perform basic removal and replacement of sensors, cables, and signal conditioning unit boards on his own. Without the installation experience, 1 day's training should suffice for that level of maintenance. Some consultation might be necessary if the problem must be traced to a board or sensor. But, if adequate spares are available, the problem measurement's sensor and board can both be replaced, negating the need for complete isolation/confirmation.

For complete installation/activation, including DCP programing and test set usage, a 3-4 day course developed by the senior author is recommended.[2] Trainees must be experienced electronics technicians (at least GS-7 level) and some digital experience is highly desirable. A step-by-step guide can then be followed as an aid to installation/activation.[3]

Depot-level maintenance plans have also been developed for various numbers of fielded RAWS and are available from Boise Interagency Fire Center (BIFC).[4] [5]

DATA RETRIEVAL

Weather data transmitted from any of the RAWS sites are available from the NESS computer to any site having a suitable terminal and telephone lines, almost instantaneously after transmission. The user pays only for the cost of the phone call and needs only a simple 300 baud, ASCII terminal to complete the data acquisition link. The data from any site or sites are thus available at any location or locations.

---

[1]Vance, Dale, and J.R. Warren. 1978. A remote automatic weather station for fire weather monitoring--development and test report. Boise Interagency Fire Center, Boise, Idaho.

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[3]Warren, J. R. 1979. DCP installation/activation procedure. Boise Interagency Fire Center, Boise, Idaho.

[4]Warren, J. R. 1978. Implementation plan for remote automatic weather stations (RAWS) for USFS users. Boise Interagency Fire Center, Boise, Idaho.

[5]Warren, J. R., and Duane Herman. 1979. Implementation plan for remote automatic weather stations (RAWS). Boise Interagency Fire Center, Boise, Idaho.

The data from NESS is presented in ASCII as either exadecimal letters aa through oo (ASCII column 5) for aBarge stations, or as decimal numbers 000 through 55 (ASCII column 4) for Handar stations. In both cases iere are 256 levels (8 bit encoding) to represent zero to ıll scale. The appropriate look-up table must be used to ıanually convert either type printout into usable data. ›igital data are treated differently. For additional details, sers should obtain descriptive material by the authors[6 7] nd should contact one of the authors for explicit, detailed ıstructions.

Because many FS, BLM, and State users utilize and have ccess to the AFFIRMS, an automatic data transfer system om the NESS computers to AFFIRMS is being nplemented. When completed, all RAWS data will be eadily available via the existing AFFIRMS without ıe need for separate user terminal access and phone alls to NESS. Meanwhile, data are daily being entered ıanually into AFFIRMS.

Data may also be retrieved from the satellite by the ser's own earth station. The stations consist of a 5-meter approximately 15-ft) parabolic antenna, a 6-foot (1.8-m) quipment rack (containing receiver, demodulator, nd minicomputer), and a user terminal. Stations have een installed and are in operation by Colorado State Iniversity, Fort Collins; California Department of orestry, Sacramento; and BLM, Boise, Idaho. The tations receive from only one satellite (unless a second ntenna system is installed). The output also contains iagnostic information for individual RAWS. The earth tations cost approximately $50,000.

RAWS AVAILABILITY

There are currently two suppliers of FS/BLM RAWS: .aBarge, Inc. and Handar, Inc. The 10 evaluation stations nd the 10 additional stations that are all operational were rocured from LaBarge. The Handar stations have a imilar instrument complement, a NESS-certified ›CP, and are anticipated to be satisfactory for field use. Iandar DCP's have been used successfully in Bureau of leclamation stations. Several Handar stations are on rder by the FS and will be observed by FS/BLM engineers › determine their performance.

The RAWS manufactured by the two firms have the same ıeasurement capability, but DCP's are different: a LaBarge ›CP requires a LaBarge test set; a Handar DCP requires Handar test set.

The cost of either RAWS is currently approximately 10,000 each, depending on quantity and a few options. ›SA procurement is available or is being processed for oth stations. Other companies have the capability to upply similar stations, but, at this time, do not have a ›AWS meeting FS/BLM requirements.

Details on the formats and procurement considerations re described in a special report by the authors, which as had wide user distribution.[6] The reference should be ›viewed prior to initiating procurement action.

Operation of RAWS requires a channel and time slot ssignment from NESS and a frequency allocation from the ser agency.

RAWS TECHNOLOGY

The RAWS uses satellite communications, solar energy, microprocessor control, and integrated circuits, coupled with more traditional electronics and meteorological sensors. Twenty-five years ago there were no man-made satellites in orbit, no microprocessors, and no integrated circuits. Solar panels were laboratory or experimental--not practical, working units. These technologies are now used routinely and in the case of RAWS sit alone in some very remote locations and perform reliably.

POTENTIAL OF RAWS

RAWS has the potential for Nation-wide use as part of the National Fire-Danger Rating System. It is ideal for that application because the stations can be set up at any desired location and the data automatically entered into the AFFIRMS. This specific application has been the impetus to the development of RAWS.

RAWS can also be set up in a grid or network of stations to provide detailed weather data over a specified area. Areas with special considerations--high values, frequent fires, daily wind shifts, and so on--might warrant such a network. A network of stations has been proposed for the Firescope area in southern California. A network might also be used for research of certain weather or other characteristics of an area.

Individual stations or a few stations can be used to determine the weather conditions prior to and during prescribed burns, spraying operations, and so on. A simple check of the weather in the area via RAWS may eliminate the need to drive considerable distances to manually check conditions. Thus energy as well as time and expense may be conserved. Likewise, false starts can be reduced and better crew utilization achieved.

The use of properly maintained and calibrated RAWS offers the potential for better standardization of weather measurements. Work with RAWS has indicated that there are wide variations in the use, calibration, maintenance, and accuracy of manual stations.

RAWS are readily adaptable for any remote, automatic data gathering need--not just weather. Various types of instruments and sensors could interface with RAWS to provide data from a variety of sources and areas. (The use of GOES must be related to environmental needs, which includes a lot of applications.)

RAWS may be used in an interrogate mode instead of on a self-timed schedule. Under the interrogate mode, data can be acquired on signal, schedules changed, data collection frequency-related to conditions, and so on. (The interrogated stations cost more than the self-timed stations).

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[6]Warren, J. R., and Dale Vance. 1979. Remote automatic weather station (RAWS) procurement, use configurations, and data formats. Boise Interagency Fire Center, Boise, Idaho

[7]Warren, J. R. 1979. RAWS data acquisition. Boise Interagency Fire Center, Boise, Idaho

An emergency alarm system may be included that will cause the RAWS to transmit on the emergency channel under certain conditions or when selected parameters exceed specified values. Water levels, high winds, high or low temperatures, and so on, could all serve as alarm indicators.

Fire-weather forecasters have identified a need for portable RAWS that could be readily set up in remote locations around large fires. These stations would be simpler than conventional RAWS and provide basic measurements of the local weather, including the fire's influence. The portable RAWS could be readily adapted with a minimum of development cost from the current RAWS technology and components.

RAWS is readily adaptable for use with other systems. For example, properly located RAWS coupled with the automatic lightning detection system (ALDS) could indicate the probability of lightning fire starts. That prediction could then be used to determine the need for infrared (IR) detection flights over the area of concern. The three systems working together could help land managers determine the probability of ignition, and the number, location, and size of lightning-caused fires. Properly located RAWS would also be invaluable to those using fire rate-of-spread models for ongoing wildland fires.

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APPENDIX I

DCP CHARACTERISTICS

Item	Specification
Transmit frequency	401.7 to 401.85 MHz
Channel spacing	1.5 kHz
Frequency stability, long term	1 p/m per year
Spurious outputs and harmonics	-50 dB (below carrier)
Modulation	Phase shift keyed (PSK)
Phase shift magnitude	±60° (±10°) with a transition time of 20 (±10) microseconds
Output bit rate	100 ± 1 bit/s, Manchester encoded
Output format	5 seconds of clear carrier, 2.56 seconds of Manchester encoded clock pulses, 15 bit maximal linear sequence (MLS) of 100 0100 1101 0111, 31 bit CDCP ID address up **to 2,000** bit data message, and three ASCII EDT (end of transmission) pulses
Transmitter fail safe feature	Transmitter will automatically power down after a 90-second transmission interval (independently of microprocessor control)
Coding	Data encoded into eight-bit bytes to ASCII format
Parity	Even or odd (selectable)
Message intervals	Selectable (by constant entered from test set) from 15 min to 63 h, 45 min (up to 255 increments) in 15 min increments
Message interval accuracy	1 p/m per year
Accuracy of initial transmission	±1 second (controlled by operator)
Emission classification	1.5F9/5

APPENDIX 2

RAWS MEASUREMENT SPECIFICATIONS

1. **Cumulative Precipitation** (Precip.)
   - Range: 0.01 to 99.99 inches
   - Accuracy: ±0.01 inches (rainfall intensity up to 2 inches in 1 h)
2. **Windspeed**
   - **Range:** 0-100 mi/h
   - ***Accuracy:** ±2.5 percent - typical; ±5.0 percent - maximum
   - **Averaged:** 2 min time - weighted
   - **Threshold:** 1 mi/h
3. **Wind Direction** (WD)
   - Range: 0-540°
   - *Accuracy: ±5.5 percent - typical; ±9.2 percent - maximum
   - Averaged: 2 min time - weighted
   - Threshold: 1 mi/h windspeed
4. **Fuel and Air Temperature** (FT and AT)
   - Range: -30 to +70° C
   - Accuracy: ±1° C (±1 percent) - typical; ±2° C (±2 percent) - maximum
5. **Relative Humidity** (RH)
   - Range: ±3 percent - typical; ±5 percent - maximum
6. **Barometric Pressure**
   - Range: 24 to 31 inches of mercury
   - Accuracy: ±0.070 inches of mercury (±1.0 percent) - typical; ±0.100 inches of mercury (±1.4 percent) - maximum
7. **Battery Monitor**
   - Range: 8.9 to 15.0 volts DC
   - Accuracy: ±0.2 VDC - typical; ±0.3 VDC - maximum

*A tolerance of ± one table value applies for low range readings (±bit A/D converter limit).

Warren, John R., and Dale L. Vance
1980. Remote automatic weather station for resource and fire management agencies. USDA For. Serv. Gen. Tech. Rep. INT-116, 11 p. Intermountain Forest and Range Experiment Station, Ogden, Utah 84401.

A weather station that operates automatically in remote areas, without power or communication lines, has been developed and is now commercially available. Remote Automatic Weather Stations (RAWS) transmit precipitation, windspeed, air temperature, fuel temperature, humidity, and barometric pressure data via satellite. Data are received at Wallops Island, Va., and stored at the World Weather Building, Maryland. Data may be acquired by direct dialing or through the AFFIRMS fire forecasting program of the USDA Forest Service.

KEYWORDS: weather stations, meteorological data acquisition, fire weather, environmental data, satellite data transmissions

The Intermountain Station, headquartered in Ogden, Utah, is one of eight regional experiment stations charged with providing scientific knowledge to help resource managers meet human needs and protect forest and range ecosystems.

The Intermountain Station includes the States of Montana, Idaho, Utah, Nevada, and western Wyoming. About 273 million acres, or 85 percent, of the land area in the Station territory are classified as forest and rangeland. These lands include grasslands, deserts, shrublands, alpine areas, and well-stocked forests. They supply fiber for forest industries; minerals for energy and industrial development; and water for domestic and industrial consumption. They also provide recreation opportunities for millions of visitors each year.

Field programs and research work units of the Station are maintained in:

Boise, Idaho

Bozeman, Montana (in cooperation with Montana State University)

Logan, Utah (in cooperation with Utah State University)

Missoula, Montana (in cooperation with the University of Montana)

Moscow, Idaho (in cooperation with the University of Idaho)

Provo, Utah (in cooperation with Brigham Young University)

Reno, Nevada (in cooperation with the University of Nevada)

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**Intermountain
Forest and Range
Experiment Station**

General Technical
Report INT-117

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Downed Dead Woody Fuel and Biomass in the Northern Rocky Mountains

James K. Brown
Thomas E. See

THE AUTHORS

JAMES K. BROWN received his bachelor's degree from the University of Minnesota in 1960, his master's from Yale University in 1961, and his Ph.D. from the University of Michigan in 1968, all in forestry. From 1961 to 1965, he did research on field measurement of fuel properties and fire-danger rating systems while with the Lake States Forest Experiment Station. In 1965 he transferred to the Northern Forest Fire Laboratory, Missoula, Mont., where he conducted research on the physical properties, inventory, and prediction of fuels. In 1979 he became leader of a fire effects and use work unit in Missoula.

THOMAS E. SEE received his bachelor's degree in forestry from Northern Arizona University in 1972 and his master's degree in forest biometrics from the University of British Columbia in 1974. He has done research and development work with North American Aviation, Inc., Mattell Inc., and Federal Electric Corporation. He managed computer systems at Virginia Polytechnic Institute and Mississippi State University, where he also taught. From 1978 to 1980 Mr. See investigated forest fuel dynamics at the Northern Forest Laboratory, Missoula, Mont. He is currently an operations analyst in Aviation and Fire Management, USDA Forest Service, Pacific Northwest Region, Portland, Oreg.

ACKNOWLEDGMENT

Many people helped with this study in various ways. It involved an extensive effort in training field crews and inventorying and processing data. The commitment, enthusiasm, and cooperation shown by the Region 1 (Northern Region) Fire Management, Timber Management, and Data Processing groups made the study possible. Cameron Johnston contributed significantly to this study as well as to the analysis on size distribution of large fuel. Special thanks are given to Jack Puckett, Joanne McElfresh, Dick Deden, Jim Laux, and Dennis Simmerman.

RESEARCH SUMMARY

Weights and volumes of downed woody material in diameter classes of one-fourth to 1, 1 to 3, and greater than 3 inches and forest floor duff depths were summarized from extensive inventories in northern Idaho and Montana. Biomass loadings are shown by cover types and habitat types within National Forests. Total downed woody biomass east of the Continental Divide ranged from 5 tons per acre in ponderosa pine to 23 tons per acre in spruce-fir. West of the divide, loadings range from 13 tons per acre in ponderosa pine to 33 tons per acre in cedar-hemlock. Duff depths for cover types ranged from 0.5 to 1.5 inches or approximately 10 to 25 tons per acre. Sixty percent of biomass greater than 3 inches diameter displayed some decay. Inasmuch as 10 tons per acre is considered desirable for on-site retention, spruce-fir and larch-grand fir cover types had the greatest excesses of biomass for utilization. Relationships proved ineffectual for predicting loading from stand age, slope, aspect, and elevation. Loadings generally increased with increased productivity, but varied greatly with stand age. The generality that dead fuels tend to become predictably high in overmature stands, but unpredictable in young immature and mature stands was supported. Forest fuel succession is discussed in relation to tree mortality, fuel buildup, and depletion.

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INTRODUCTION

Downed dead woody fuel and biomass consists of dead twigs, branches, stems, and boles of trees and shrubs that have fallen and lie on or near the ground. To land managers, downed dead woody material is both a benefit and detriment. It is beneficial as a source of nutrients in the ecosystem, shelter and food for wildlife, soil stabilization, shade for young trees, fuel for useful purposes, and forest products. It is detrimental when excessive amounts accumulate causing unwanted wildfire hazards, obstructions to people and wildlife, and a tieup of nutrients.

Knowledge of downed woody material quantities can be used in such activities as determining stand prescriptions, evaluating possibilities for utilization of firewood, pulpwood, and other products, and appraising fuel and fire behavior potentials. For example, in determining stand prescriptions, knowledge as to whether excessive or deficient quantities of downed woody material are expected can aid in managing fuels and in setting target amounts of woody material to be left on site. Consideration should be given to maintaining favorable microbial populations for long-term site quality (Harvey and others 1979), needs of wildlife (Thomas 1979), grazing opportunities, wildfire hazards, and to other factors having either a positive or negative impact. Although evaluation of these factors may be highly judgmental, knowledge of woody quantities can faciliate communications and decisions in the planning process.

This paper reports on quantities of downed woody material found in western Montana and northern Idaho and examines the predictability of accumulated dead biomass. The information on downed woody quantities is based on inventories conducted by the Forest Service Region 1 (Northern Region) over a 6-year period. The terms "biomass" and "fuel" and the concept of fuel accumulation and succession are discussed next to help in understanding the findings from this study. Findings are reported in two major sections, Loading and Volume Summaries and Loading and Stand Relationships.

FUEL ACCUMULATION AND SUCCESSION

The concepts of fuel accumulation and succession are important in establishing fuel management strategies; so an understanding of them is desirable. General usage of "fuel accumulation" implies an increase in fuel loading and associated fire hazard over time. The term often is loosely used but the concept is of considerable concern to land managers. A countermeasure to "fuel accumulation" involves deterioration and decay. Fuel succession refers to change in fuel properties, such as loading, size distribution, and live-to-dead ratios, and embodies the concepts of both accumulation and decay.

"Forest biomass" and "forest fuels" both refer to vegetation, but the two terms frequently refer to different amounts of plant material. Biomass refers to total weight of vegetation. In the absence of disturbances, biomass increases predictably with time because photosynthesis is perpetual. Forest fuel is organic material that could contribute to combustion. In this sense, only certain kinds and parts of vegetation are fuels. The amount of vegetation that is available for combustion depends on such factors as fuel size, moisture content, and arrangement. In most forest fires, some vegetation is unavailable for combustion; for example, most of the biomass produced on a forest site is frequently tied up in standing tree boles and is unavailable except where fuels are ideally arranged. This can cause confusion because seldom is all vegetation available for combustion. The terms "forest fuels" and "biomass" are often used synonymously.

Live and dead fuels, as well as small and large fuels, can follow different successional patterns. Live fuels can be divided into two groups: (1) crown fuels consisting of foliage and fine branches and (2) surface fuels consisting of grasses, forbs, and shrubs. Coverage and biomass of herbaceous vegetation and shrubs appear to increase during development of some stands and to decrease in others. Increases and decreases apparently depend on site conditions and species existing before disturbance (Lyon and Stickney 1976; Habeck 1976), as well as on

the nature of disturbance. On mesic sites, biomass of herbs and shrubs tends to peak during early stages of stand development and to decrease after that.

Once crown canopies are closed, loadings of fine dead fuels, such as foliage, bark flakes, and twigs and stems less than about 1.0 inches (2.5 cm) in diameter, remain fairly constant in the forest floor litter layer (Jeske and Bevins 1979). Small oscillations in loading occur (Fahnestock 1976). This pattern appears logical because dead needles and leaves are shed annually along with some live and dead twigs. Variable production of foliage and varying wind and snow effects probably cause the oscillations in loading.

Dead branches and tree boles accumulate on the ground in response to natural causes of mortality and factors causing downfall (Brown 1975). Causes of mortality such as fire, insects, disease, suppression or natural thinning, and wind and snow damage impact stands in a rather haphazard manner. Thus, buildup of downed dead biomass also occurs in a haphazard manner and is not necessarily related to stand chronology.

SOURCE OF DATA

In 1972, the Forest Service Region 1 incorporated procedures for inventorying downed woody material into their forest inventory program. This publication is based on data collected over a 6-year period from 1972, and was made possible by a system of edited data records stored on magnetic tape. Downed woody material was estimated using the planar intersect method described by Brown (1974a) and Brown and Roussopoulos (1974) and included in the Stand Examination Handbook (USDA Forest Service Region 1 1978). The handbook provided for estimation of the following fuel variables:

1. Loading of 0.25- to 0.99-inch (0.6- to 2.5-cm) material;
2. Loading of 1.0- to 2.99-inch (2.6- to 7.5-cm) material;
3. Loading of 3.0-inch (7.6-cm) and greater sound material;
4. Loading of 3.0-inch (7.6-cm) and greater rotten material; and
5. Depth of forest floor duff (02 horizon, also called F and H layers of the forest floor, which is everything beginning at the bottom of the loosely cast litter layer to the mineral soil; the 01 horizon or litter layer is excluded).

Material less than 0.25 inch (0.6 cm) in diameter was not inventoried. The size classes correspond to standard timelag moisture response categories (Fosberg 1970) used especially in the National Fire-Danger Rating System (Deeming and others 1977). Rotten material includes downed pieces that show rot visibly on the outside. The planar intersect method furnished direct estimates of volumes that were converted to weights assuming the following densities:

Fuel	Density (lb/ft^3)
0.25 to 0.99 inch	30
1.0 to 2.99 inches	25
3.0 inches and greater:	
Sound	25
Rotten	19

Inventoried fuel data were gathered under two sampling plans:

1. *Forest inventory (stage 1).* — This inventory is conducted for timber management planning on a Forest-wide basis (Stage and Alley 1972). Sample plots are located on a 5 by 10 chain grid in randomly chosen management subcompartments. Each sample point represents 5 acres. Over several years, all National Forests in Region 1, underwent a forest inventory. Nearly all Forest Service land outside of classified wilderness was sampled. Because sample areas were randomly chosen, inventory summaries are representative of Forest-wide conditions.

The Coeur d'Alene (now part of the Idaho Panhandle), Beaverhead, and Lewis and Clark National Forests were inventoried without fuel measurements and the Custer National Forest data were unavailable to us. Thus, for these Forests, loading summaries from the Forest Inventory were not possible in this report. The Colville National Forest, now in Region 6 (Pacific Northwest Region), but formerly in Region 1 (Northern Region), was inventoried and appears in this report.

2. *Stand examination (stage II).* — This inventory is conducted for project activities, such as timber sale preparation, forest thinning, and restocking surveys. Plots are systematically located in stands that individual Ranger Districts select for management activities. Thus, this inventory is biased toward those stands. Although the kind of stands sampled varies by Ranger District, most examinations are conducted in anticipation of timber sales.

Many stands selected for timber sales are "high risk"; a large amount of mortality is expected before the next rotation. In stands considered "high risk," some mortality has already occurred and downed woody fuels may have accumulated above normal amounts.

The goal for sampling precision is to locate enough plots to provide a standard error of the estimate of timber volume within 20 percent for stands less than 20 acres in size and within 15 percent for larger stands. Those goals are not always met.

In conducting stand examinations, fuel information is not always collected. It is more often collected for timber sale and thinning preparations than for restocking surveys. For this study, only fuel information recorded on the timber management form (R1-2410-15B, 4/75) was analyzed. Large amounts of fuel data have also been collected on the fire management form (R1-5100-07), but were not centralized on data tapes for ready access.

For both the Forest Inventory and Stand Examination sampled fuels were, for the most part, naturally occuring rather than slash. On many Forests, considerably less than 25 percent of the Forest Inventory data came from cutover areas as shown in the following tabulation:

National Forests	Percent sample points in cutover photo interpretation classes
Kootenai, Flathead, Colville	24
Lolo, Bitterroot	17
Clearwater, Kaniksu, St. Joe, Deerlodge, Helena	7
Custer, Gallatin, Nezperce	1.5

In using the fuel summaries reported here, the difference between the Forest Inventory and Stand Examination data can

have important implications. The key distinction is that the Forest Inventory data represent Forest-wide stand conditions; whereas, the Stand Examination data primarily represent stands selected for timber harvesting and, to a lesser extent, thinning. Discussions with Range District timber personnel indicated that a large proportion of stands selected for timber sale were "old growth" or "high risk."

Analysis was directed at preparation of tables summarizing fuel loadings by National Forests and at examining the relationships between loadings and stand descriptors, such as cover type, habitat type, age, aspect, elevation, and site productivity. For the summary tables, the Forest Inventory data were pooled by cover types and habitat types. Sample statistics were computed for fuel characteristics from the pooled data. For the Stand Examination data, mean fuel characteristics were computed by stands. Because stand selection was biased, data were not pooled by cover types and habitat types but evaluated on a stand basis.

Relationships between fuel characteristics and stand descriptors were analyzed using the Forest Inventory data because it represented a random sample that was free from known bias. In investigating relationships, fuel characteristics were treated as stand means and number of plots per stand were used as weights.

LOADING AND VOLUME SUMMARIES

Forest Inventory

Loadings of downed woody material and duff depth were summarized by cover types and by habitat type groups. Readers who are interested in statistics for individual National Forests should turn to appendix I. Variation in the data and correlations between fuel variables are discussed in appendix II. The following main text presents summaries for groups of National Forests, such as those east of the Continental Divide (Eastside) and west of the Continental Divide (Westside). Total loading is the sum of the 0.25- to 0.99-inch (0.6- to 2.5-cm), 1.0- to 2.99-inch (2.6- to 7.5-cm), and over 3-inch (7.6-cm) downed woody material. For convenience, downed woody material less than 3 inches (7.6 cm) in diameter will be referred to as small fuel, and downed woody material 3 inches and greater will be referred to as large fuel. For proper application of these summaries, remember that they describe downed woody biomass accumulated primarily in the absence of harvesting and thinning.

Cover types. — Cover types conform to USDA Forest Service standard forest survey types. Cover types were named for the species representing a plurality of basal area in a stand. The following cover types were encountered in either the Forest Inventory or Stand Examination with sufficient data to merit summary:

C-H	Cedar-hemlock	*Thuja plicata* Donn- *Tsuga heterophylla* (Raf.) Sarg.
DF	Douglas-fir	*Pseudotsuga menziesii* (Mirb.) Franco
L	Larch-grand fir	*Larix occidentalis* Nutt.- *Abies grandis* (Dougl.) Lindl.
LP	Lodgepole pine	*Pinus contorta* Dougl.
PP	Ponderosa pine	*Pinus ponderosa* Laws.
S-F	Spruce-subalpine fir	*Picea engelmannii* Parry- *Abies lasiocarpa* (Hook.) Nutt.
WP	Western white pine	*Pinus monticola* Dougl.

Habitat type groups. — Loadings of downed woody material were not expected to vary significantly between many habitat types. However, loadings were expected to vary by groups of habitat types that reflect a gradient in moisture and temperature. Thus, the habitat types described by Pfister and others (1977) were grouped into the following categories for relating to loading:

1. Limber pine (*Pinus flexilis*); ponderosa pine, and Douglas-fir/bunch grass types.
2. Dry site Douglas-fir and moist site ponderosa pine.
3. Moist site Douglas-fir.
4. Cool sites dominated by lodgepole pine; dry, lower elevation subalpine fir.
5. Moist site, lower elevation subalpine fir.
6. Cold, moist site upper elevation subalpine fir.
7. Warm, moist sites; mostly cedar-hemlock.

The habitat type fire groups developed by Davis and others (1980), based on similarity of tree succession, were used as a basis for grouping habitat types in this paper. The habitat types comprising these groups and their correspondence to the fire groups developed by Davis and others (1980) are shown in appendix III. (The last page of this document lists the common name, scientific name, abbreviation, and ADP code for each habitat type mentioned in this publication.)

Generalities and comparisons. — Total downed woody loadings from moist, productive sites tend to be greater than from drier, less productive sites as shown in figures 1 and 2. The cedar-hemlock type supported the greatest loading followed by spruce-fir. Ponderosa pine displayed the smallest loading (fig. 3). Eastside Forests consistently have smaller loadings than Westside Forests with one minor exception in habitat type Group Three.

Total loadings vary more among cover types than among habitat type groups as seen in comparing figures 1 and 2. This seems reasonable because downed woody material accumulates almost entirely from trees; shrubs contribute only slightly to downed woody material. Cover types more accurately reflect tree species occupying sites than habitat types. Tree species influence downed woody accumulations to the extent that tree size and susceptibility to mortality relate to species.

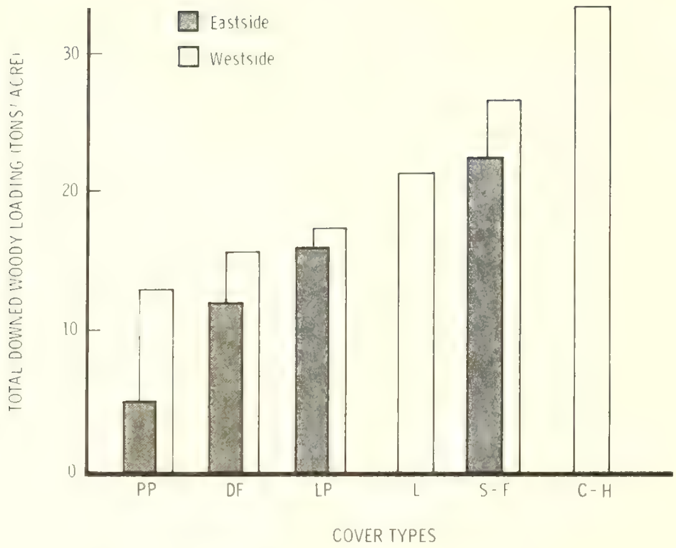

Figure 1. — Total downed woody loadings by cover type for Westside and Eastside National Forests.

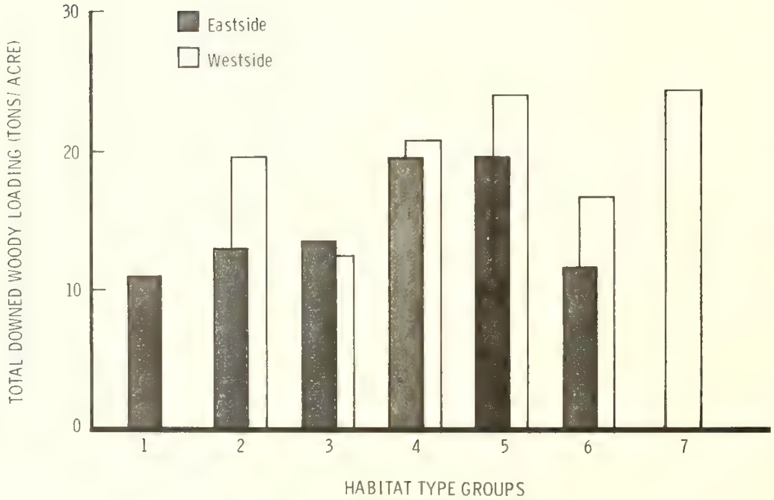

Figure 2. — Total downed woody loadings by habitat type group for Westside and Eastside National Forests.

Figure 3. — Loadings of total downed woody material varied widely as illustrated: 1 ton/acre in a ponderosa pine stand (top); 12 tons/acre in a lodgepole pine stand (middle); and 40 tons/acre in a spruce-fir stand (bottom).

Small downed woody material did not vary greatly among cover types and among habitat type groups (tables 1 and 2). Considering an additional loading for 0- to 0.25-inch (0- to 0.6-cm) material, which should be small compared to the 0.25- to 3-inch (0.6- to 7.5-cm) material, loadings of less than 3-inch (7.6-cm) material can be expected to average from 3 to slightly over 4 tons/acre (0.67 to 0.90 kg/m^2) for all forest types.

Duff depths averaged about 0.5 to 1.5 inches (1.3 to 3.8 cm). Assuming a bulk density of 8 lb/ft^3 (0.13 g/cm^3), these depths correspond to loadings in the neighborhood of 10 to 25 tons/acre (2.2 to 5.6 kg/m^2). Cover types and habitat type groups having the greatest total downed woody loadings also have the greatest duff depth (tables 1 and 2).

Percent rotten displayed little difference among cover types and habitat type groups (tables 1 and 2). Considering the imprecise method for classifying sound and rotten material and the variation in percent rotten among stands, a figure of 60 percent rotten is a reasonable estimate representing all forest types. During field inventories, degree of rot was not measured. Thus, estimates of percent rotten include pieces showing only a small amount of surface decay to pieces entirely in a decayed crumbly state.

Table 1.—Average downed woody loadings, duff depths, and percentages rotten from the Forest Inventory by cover type and National Forest, Westside and Eastside

Cover type[1]	Westside Forests						Eastside Forests					
	Number observed	Downed woody			Duff depth	Rotten large	Number observed	Downed woody			Duff depth	Rotten large
		Small	Large	Total				Small	Large	Total		
		Tons/acre			Inches	Percent		Tons/acre			Inches	Percent
PP	944	2.5	10.4	12.9	0.6	61	184	1.1	3.9	5.0	0.6	70
DF	5,762	2.8	12.9	15.7	.9	63	2,475	2.4	9.6	12.0	1.0	63
LP	4,172	3.1	14.4	17.5	1.1	59	3,400	2.2	13.9	16.1	1.1	55
L	5,381	3.6	17.7	21.4	1.2	58	—	—	—	—	—	—
S-F	3,597	2.9	23.8	26.7	1.4	52	712	2.5	20.2	22.7	1.3	52
C-H	1,727	4.0	29.4	33.4	1.4	57	—	—	—	—	—	—

[1]PP = Ponderosa pine, *Pinus ponderosa* Laws.
DF = Douglas-fir, *Pseudotsuga menziesii* (Mirb.) Franco.
LP = Lodgepole pine, *Pinus contorta* Dougl.
L = Larch-grand fir, *Larix occidentalis* Nutt.-*Abies grandis* (Dougl.) Lindl.
S-F = Spruce-subalpine fir, *Picea engelmannii Parry-Abies lasiocarpa* (Hook.) Nutt.
C-H = Cedar-hemlock, *Thuja plicata* Donn-*Tsuga heterophylla* (Raf.) Sarg.

Table 2.—Average downed woody loadings, duff depths, and percentages rotten from the Forest Inventory by habitat type group and National Forest, Westside and Eastside

Habitat type groups[1]	Westside Forests						Eastside Forests					
	Number observed	Downed woody			Duff depth	Rotten large	Number observed	Downed woody			Duff depth	Rotten large
		Small	Large	Total				Small	Large	Total		
		Tons/acre			Inches	Percent		Tons/acre			Inches	Percent
1	—	—	—	—	—	—	577	2.3	8.5	10.8	1.1	66
2	2,569	3.6	15.9	19.5	0.8	54	1,234	2.5	10.5	13.0	1.0	59
3	3,287	2.4	10.0	12.4	.9	54	1,151	2.1	11.3	13.4	.9	59
4	5,348	3.2	17.3	20.5	1.1	56	2,320	2.4	17.0	19.4	1.2	56
5	3,937	2.8	21.0	23.8	1.4	53	870	1.9	16.9	18.8	1.0	54
6	474	2.1	14.3	16.4	1.0	48	123	2.1	9.4	11.5	.7	57
7	5,460	3.6	20.3	23.9	1.3	57	—	—	—	—	—	—

[1]1. = Limber pine *(Pinus flexilis);* ponderosa pine and Douglas-fir/bunch grass types.
2. = Dry site Douglas-fir and moist site ponderosa pine.
3. = Moist site Douglas-fir.
4. = Cool sites dominated by lodgepole pine; dry, lower elevation subalpine fir.
5. = Moist site, lower elevation subalpine fir.
6. = Cold, moist site upper elevation subalpine fir.
7. = Warm, moist sites; mostly cedar-hemlock.

Figure 4 is presented for quick reference to total loadings and for comparing total loadings among Forests. Few generalities are apparent in figure 4 except that the ranking of Forests according to loading differs among cover types. For example, the Colville N.F. displays the highest loadings by far for the cedar-hemlock, spruce-fir, and ponderosa pine cover types; yet, loadings for larch-grand fir and Douglas-fir have middle rankings. Variation in cedar-hemlock loadings is greater than in other types. The reasons for variation among Forests are not apparent from simply examining the inventory summaries. However, knowledge of stand histories would probably explain most of the real differences among Forests.

The diameters of large fuel were analyzed on a sample of commonly occurring habitat types usually associated with cover types of Douglas-fir, western larch, lodgepole pine, cedar-hemlock, and spruce-fir. Results showed that on the average, large fuels have greater diameters in larch, cedar-hemlock, and spruce-fir cover types than in Douglas-fir and lodgepole pine cover types (fig. 5). Diameters of large fuels run greater on Westside than on Eastside Forests. For example, the percentage of large fuels greater than 10 inches (25.4 cm) in diameter is:

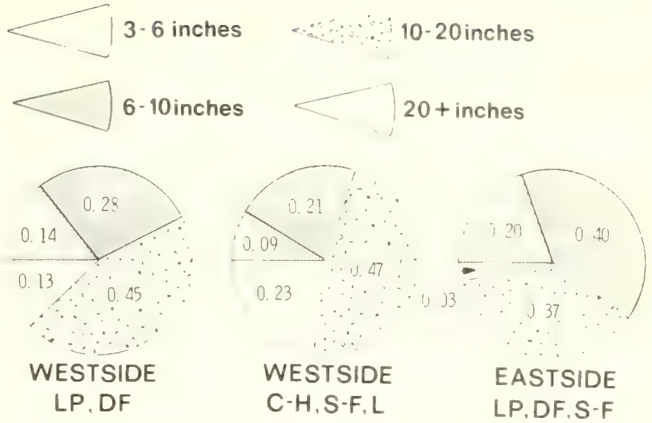

Figure 5. — Fractions of large fuel by diameter class for selected cover types on Eastside and Westside National Forests.

Location and cover type	Percentage
Westside; C-H, S-F, L	70
Westside; DF, LP	58
Eastside; S-F, DF, LP	40

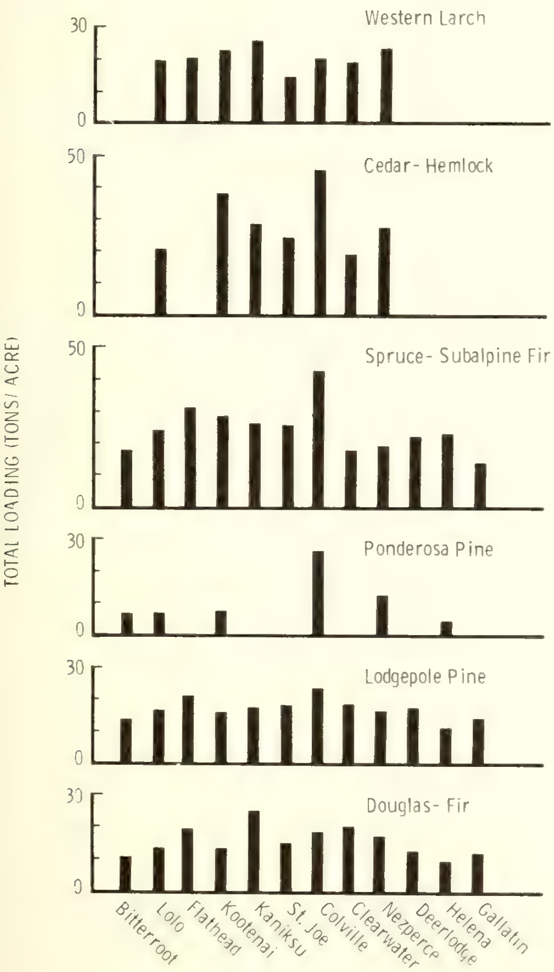

Figure 4. — Total downed woody loadings by cover type and National Forest.

A greater fraction of large fuels over 10 inches in diameter is rotten rather than sound probably because large pieces remain decayed for a larger period than small pieces. Considerable variation existed among Forests in the fractional breakdown of large fuel diameters. This could be important in applying large fuel information; thus size distribution summaries by individual Forests are shown in appendix IV.

Stand Examination

Loadings of downed woody material from Stand Examinations are summarized in appendix V for individual National Forests. The ranking of cover types according to total loadings and duff depth is the same for both Stand Examination and Forest Survey data. The cedar-hemlock type supported the greatest loadings followed in order by spruce-fir, larch, Douglas-fir, lodgepole pine, and ponderosa pine.

Loadings from Stand Examinations ranged from about the same as the Forest Inventory (representative of Forest-wide conditions) to as much as three times greater (table 3). Ratios of 1.0 indicate that stands selected for Stand Examinations contain loadings similar to average loadings for the whole Forest. Ratios highlighted in table 3 indicate Forests and cover types where stands selected for Stand Examinations tended to be high risk or decadent and to contain substantially greater loadings than the average Forest stand.

On the Bitterroot and Clearwater National Forests, Stand Examinations especially appear to have been located in high-risk stands. On most Forests, Stand Examinations in the ponderosa pine cover type displayed markedly greater loadings than the Forest Survey average for ponderosa pine. Several reasons could explain this; one possible explanation is, however, that harvestable ponderosa pine stands have undergone considerable mortality leading to an accumulation of downed woody material that is about double the Forest-wide average.

The Stand Examination data offer another approach to extrapolating loadings. If high-risk or decadent stands are of interest, the factors in table 3 can be multiplied times the loadings in appendix I. This should provide better estimates of loadings in high-risk stands. The estimates should, however, be regarded as rough approximations because the representativeness of Stand Examinations is known only generally.

Because Stand Examinations are conducted to provide information on stands identified for certain management activities, extrapolation of Stand Examinations summaries to other areas is risky without knowledge of the Forest conditions where the Stand Examinations were taken. Persons acquainted with the location of Stand Examinations may be able to understan and to make use of Forest Survey as well as Stand Examinatio summaries. To help explain where Stand Examinations wer located, the number of stands sampled by the National Fores and the Ranger District are tabulated in appendix V.

Volumes

Because volumes rather than weights may be of interes particularly for evaluating utilization potentials, table 4, sum marizing volumes per acre of woody material over 3 inches (7. cm) diameter by cover type, is presented. Volumes were calcu lated from the loadings in appendix I assuming 60 percent rotte

Table 3.—Ratios of mean total downed woody fuel loadings from Stand Examination data to Forest Inventory data. Shading indicate substantial high-risk stand conditions where loadings are substantially greater than average forest conditions

National Forests	Cover types[1]					
	DF	PP	S-F	C-H	L	LP
Bitterroot	2.3	2.0	3.1			2.1
Lolo	1.1	1.7	1.7		1.1	1.2
Flathead	1.0		1.2		1.0	.7
Kootenai	1.2	3.2	1.1	1.2	1.3	1.0
Clearwater	1.3		1.8	2.2	1.8	1.2
Nezperce	1.2	2.0	1.4	1.4	1.3	1.0
Panhandle	1.2		1.2	1.4	1.4	1.0
Helena	2.0	1.0	1.3			1.3
Deerlodge	1.0		1.2			.9
Gallatin	1.5		1.7			1.5

[1]DF = Douglas-fir.
PP = Ponderosa pine.
S-F = Engelmann spruce-subalpine fir.
C-H = Western redcedar-western hemlock.
L = Western larch-grand fir.
LP = Lodgepole pine.

Table 4.—Volumes of large downed woody material by cover type and National Forest from the Forest Inventory

National Forest	Cover types[1]					
	DF	PP	S-F	C-H	L	LP
	ft³/acre					
Bitterroot	880	500	1,530			1,160
Lolo	1,090	460	2,000	1,700	1,610	1,270
Flathead	1,620		2,720		1,720	1,780
Kootenai	1,040	560	2,470	3,390	1,980	1,370
Clearwater	1,510		1,390	1,460	1,500	1,400
Nezperce	1,380	1,020	1,680	2,180	2,100	1,410
Kaniksu	2,070		2,330	2,450	2,340	1,310
St. Joe	1,130		2,140	2,080	1,180	1,480
Colville	1,440	2,170	3,650	3,910	1,620	1,820
Helena	790	370	2,030			990
Deerlodge	1,010		1,940			1,500
Gallatin	970		1,140			1,130
Westside	1,230	990	2,260	2,840	1,680	1,360
Eastside	910	370	1,920			1,320
Western Montana	1,110	510	2,290	3,130	1,850	1,420
Northern Idaho	1,420	1,020	1,880	1,960	1,940	1,410

[1]DF = Douglas-fir.
PP = Ponderosa pine.
S-F = Engelmann spruce-subalpine fir.
C-H = Western redcedar-western hemlock.
L = Western larch-grand fir.
LP = Lodgepole pine.

for all cover types. The estimates of volume include material ranging from recently dead sound pieces to highly decayed and deteriorated pieces. Because the field observation of percent rotten included all degrees of decay, some material classed as rotten could be utilized for some purposes, such as fuel. Probably about one-third to one-half of the material classed as rotten could withstand the stresses of skidding and be suitable for fuelwood.

Estimates of volume are more accurate than weight because the planar intersect method used in the inventories provides direct estimates of volume. Weight is calculated assuming wood densities. Volume of large woody material can be calculated from ton-per-acre loadings using the formula:

$$V = \bar{w}\,(25.26\ Rf + 80) \qquad (1)$$

where:

V = volume, ft^3/acre
$\bar{w}$ = loading, t/acre
Rf = fraction of weight that is rotten.

Equation (1) was derived using wood densities of 25 and 19 lb/ft^3 (0.40 and 0.30 g/cm^3) for sound and rotten material, respectively. Volumes in decadent or high-risk stands should be greater than in table 4 as is indicated by the ratios in table 3.

Additional information on volumes, condition, and product potential of downed and standing dead wood is reported by Benson and Schlieter (in preparation)[1]. For mature stands in Montana and Idaho, they determined volumes according to no defect, sound defect, solid rot, and crumbly rot. Crumbly rot (pieces that will not hold together in logging) ranged from about 20 percent in lodgepole pine to 80 percent in larch. Benson and Strong (1977) reported on piece size and product suitability of lodgepole pine.

Volumes (million cubic feet) of large downed woody material occurring in western Montana and northern Idaho were computed using volumes in table 4 and acres of commercial forest land[2]:

Land base	Western Montana	Northern Idaho	Total
National Forest	8.7	6.2	14.9 (422,000 m^3)
All lands	12.6	12.8	25.4 (719,000 m^3)

The estimates for all lands are based on the assumption that volumes of downed woody materials on private, State, and other Federal lands are comparable to volumes on National Forest land. Data were unavailable to evaluate this assumption. Volumes of large downed woody material and acreages by cover type in western Montana and northern Idaho are presented in appendix VI.

Excess Downed Woody Material

An important question for forest managers to answer is how much downed woody material is desirable to retain on site for purposes such as nutrient cycling, wildlife habitat, and site protection. A balance is desirable between beneficial uses of downed wood in the ecosystem and detrimental influences, such as excessive fire hazard and impediments to animal and human activities. The balance is attained at some optimum quantity of downed woody material that probably varies by forest communities and management circumstances.

Although quantitative evaluation of optimum quantities has received little attention in the literature, reasonable approximations seem possible. Recent evidence by Harvey (in preparation)[3] indicates that 10 to 15 tons/acre (2.2 to 3.4 kg/m^2) of downed woody material greater than 6 inches (15 cm) in diameter is desirable to maintain high levels of ectomycorrhizal activity. This amount should not create unreasonable fire hazards; quantities greater than 15 to 20 tons/acre (3.4 to 4.5 kg/m^2) would, however, diminish fire protection efficiency.

Assuming 10 tons/acre (950 ft^3/acre) is desirable, figure 6 indicates that the larch and spruce-fir cover types contain the greatest quantities of excess downed woody material. Excess quantities were computed by subtracting 950 ft^3/acre (66.5 m^3/ha) from the large downed woody material volumes in table 4. This analysis suggests that ponderosa pine and Douglas-fir cover types are deficient in downed woody material or contain only slight excesses. Efforts to utilize downed woody biomass should not focus on these types.

In cover types supporting substantial excesses of downed wood, most or all of the quantity desired to remain on site could be rotten material. Since rotten material normally would not be sought as a product, utilization of sound and slightly decayed material should be compatible with need for leaving downed material. This could change in the future — then overutilization will become a problem to forest managers.

[1]Benson, Robert E., and Joyce Schlieter. Woody material in Northern Rocky Mountain forests: volume, characteristics, and changes with harvesting.

[2]Statistics compiled by the Resources Evaluation Unit, USDA Forest Service, Intermountain Forest and Range Experiment Station, Ogden, Utah

[3]Harvey, A.E., M.F. Jurgensen, and M.J. Larsen. Importance of quantity and type of organic reserves to ectomycorrhizae in forest soils in western Montana.

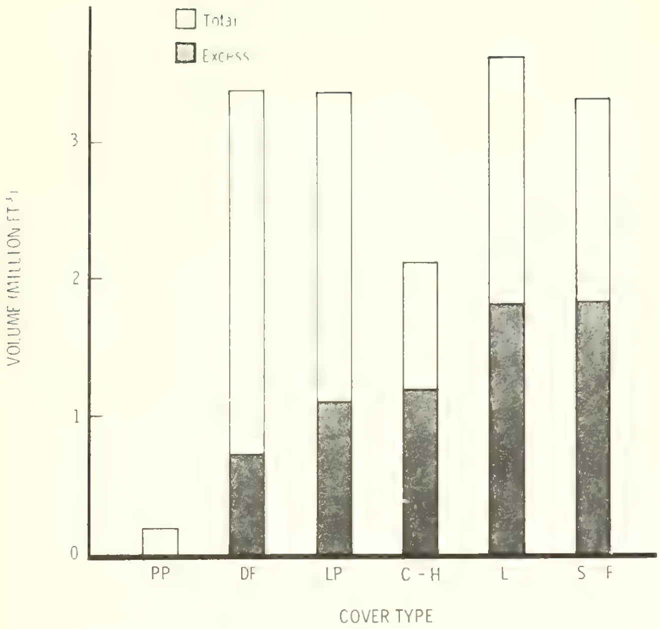

Figure 6. — Total and excess volume of large downed woody material by cover type in western Montana and northern Idaho. Excess volume is material exceeding 950 ft³/acre.

LOADING AND STAND RELATIONSHIPS

Multivariate Analyses

One of the objects of this study was the development of predictive equations for fuel loadings as statistical functions of geographic, physiographic, and environmental factors. Various models were formulated for these relationships using the variables as recorded and with suitable transformations. The down woody loadings were used as response variables both individually and in combination as small fuel load, large fuel load, and total fuel load (small and large). Stand age, slope, aspect, and elevation were used as the independent variables in the model formulation. Experience has shown that some variables should be transformed before inclusion in the models. For example, aspect was recorded as a coded observation bearing little relation to its influence on environmental conditions. A sine and cosine transformation of aspect was used to better typify this influence.

Various scatter plots and regression screens were carried out using standard plot routines and the REX Program (Grosenbaugh 1967), both available on the Lawrence Berkeley Laboratory (LBL) CDC 7600 computer. Examination of the output showed other transformations that might be appropriate, such as using the natural logarithm of down woody fuel loadings as the response variables. The chosen models were fit by a stepwise multiple linear regression program at LBL.

Very little of the observed variation in loading was explainable by any of the factors included in the models. In the event that either habitat type or cover type was masking the assumed relationships, the models were fit within these strata. Again, little of the variation in loading was explainable.

Table 5 shows typical results from the regression analysis. Regression coefficients are shown for significant independent variables. The partial F-value shows the relative contribution of that variable (Draper and Smith 1966). The R^2 indicates the percent variation explainable by the equation for the included variables. As shown in table 5, little predictive ability was available in these fits. We concluded that either the factors examined had little relation to the variation in down woody fuel loading, or other factors were masking these relationships.

Loading Versus Stand Age

A commonly espoused notion about fuel accumulation is that fuels accumulate over time attaining hazardous fire potentials as stands reach old age. We expected to observe this in analysis of the data; however, support for this notion was not found. We failed to observe any consistent relationship, pattern, or periodicity to demonstrate that downed dead woody fuel loading increases with stand age.

Analysis of the relationship between stand age and loading is complicated by ambiguities in determining stand age. Ideally, stand age would reflect time since last major disturbance by fire as well as time since origin of stand. However, this appears to happen for only a minority of stands in the Northern Rocky Mountains. All-aged stands of mixed species, which appear to represent most stands in the Northern Region, present the most uncertainties in determining age and in interpreting what it means in relation to fuel accumulation.

In analysis of the Resources Evalution data, both Resources Evaluation stand age (based on the oldest trees of species defining the type) and first component age (based on age of the species having the greatest basal area per acre) produced similar lack of correlations. Age had not been determined for the Stand Examination data; so we developed a stand age algorithm for computer processing of individual plot data. This algorithm, which determines average age of the oldest trees for species defining a cover type, might be useful for other purposes. It operated as follows:

Step 1. Determine minimum age of trees qualifying for calculation of stand age. Using the maximum age of inventoried trees up to 350 years as a basis, the minimum qualifying age is:

$$\text{Min. age} = (\text{Max. age})\,[1-0.337 + 0.000908(\text{Max. age}) - 0.00000111(\text{Max. age})^2] \quad (2)$$

When the maximum age is greater than 350 years:

$$\text{Min. age} = 0.85\ \text{Max. age} \quad (3)$$

These functions were established so that minimum age varied from approximately 0.70 to 0.85 of the maximum age.

Step 2. To prevent determination of stand age based on a very old, atypical tree, decide whether the number of trees exceeding the minimum age is an adequate sample. If the sample is inadequate, discard the oldest tree and repeat Step 1. To evaluate adequacy of sample, we arbitrarily required the following number of qualifying trees:

Total number of trees having age observations	Required number of trees exceeding minimum age
0-9	1
10-40	2
over 40	3

Table 5.—Statistics from regression analysis of total downed woody loading[1] on the independent variables slope, stand age, aspect, and elevation

Independent variable	All Groups Coefficient	All Groups Partial F[2]	Habitat Group 1 Coefficient	Habitat Group 1 Partial F	Habitat Group 2 Coefficient	Habitat Group 2 Partial F	Habitat Group 3 Coefficient	Habitat Group 3 Partial F
Constant	24.5		-0.60		10.6		22.0	
Slope	-1.6	76.8		0.1	-.34	14.4		2.5
Age	0.012	9.2	.34	17.7	.51	108	-.27	12.0
Cos(aspect)	2.8	34.2		3.7	.77	5.6	2.1	22.3
Elevation		2.2	.10	4.5		.5	-.17	18.9
Sin(aspect)		1.9	1.4	6.8		.2		7.1
	$R^2 = 0.05$		$R^2 = 0.06$		$R^2 = 0.05$		$R^2 = 0.09$	

Independent variable	Habitat Group 4 Coefficient	Habitat Group 4 Partial F	Habitat Group 5 Coefficient	Habitat Group 5 Partial F	Habitat Group 6 Coefficient	Habitat Group 6 Partial F	Habitat Group 7 Coefficient	Habitat Group 7 Partial F
Constant	39.0		15.9		18.0		10.9	
Slope	-3.0	239	-1.7	184	-1.7	102	-4.1	121
Age		1.9	.69	168	.65	81		2.4
Cos(aspect)	-2.6	38.3	.87	7.8	5.1	140	-4.7	32
Elevation	-.15	26.6	.15	31.3	.25	25	.57	46
Sin(aspect)	-6.1	224		.4	-2.1	65	5.2	43
	$R^2 = 0.15$		$R^2 = 0.08$		$R^2 = 0.09$		$R^2 = 0.13$	

[1]Total downed woody loading was transformed into natural logarithms for individual habitat type groups, but was untransformed for All Groups.
[2]Statistical significance of the Partial F for variable selection is based on F (1.00, 0.95) = 3.84

Step 3. Calculate average age of qualifying trees exceeding minimum age.

Scattergrams between stand age and small woody biomass, large woody biomass, and duff depth were examined for age partitioned into 1-, 20-, and 50-year classes. The data were stratified by individual Forests, Eastside and Westside Forests, and the entire Region. Results were primarily a wide scatter of points as shown in figure 7. Interestingly, all age classes exhibited high within-class variability; loadings ranged from zero to some high value. Usually, the extreme loadings were similar among age classes. Sometimes a particular cover type in a particular Forest showed periodicity between loading and stand age, but a consistent pattern was not evident.

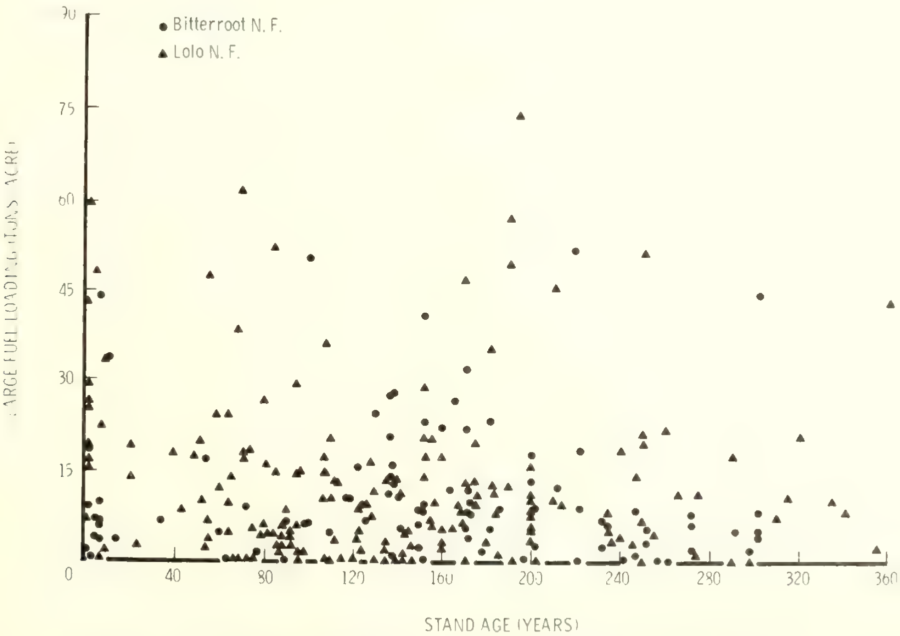

Figure 7. — Scattergrams between average stand large fuel loadings and stand age for all cover types in Region 1, based on Forest Survey data.

The large variability within age classes may have masked some relationships. Hoping to circumvent this problem, the top 20th percentile loadings of each age class were plotted for individual Forests and the entire Region. As before, some periodicity between loading and stand age was suggested, but consistent trends did not emerge.

The failure to find a substantive relationship between loading and stand age is probably due to two factors. One, mortality and downfall of trees, occurs at all stand ages, not just in old stands. Two, high variability among stands obscures and weakens relationships that might exist.

Few studies aimed at determining the relationship between downed woody fuel loading and stand age have been conducted. Available evidence, however, indicates a lack of consistent pattern in buildup and decline of fuel loading with stand age. In stands on dry-to-moist sites in the Selway-Bitterroot Wilderness of Idaho, Habeck, (1976) found that for most cover types, loadings of large downed woody material were greater in mature stands than in developing stands. In stands of mixed species in the Paysayten Wilderness, Washington, Fahnestock (1976) found that loadings of large material ranged from low to high in developing stands. Loadings were least in mature stands, then increased over the period that stands were 200 to 400 years of age.

Probably more data on fuel succession exist for lodgepole pine than any other type and it exemplifies the lack of consistent patterns. In figure 8, median large fuel loadings were normalized using the maximum loading for each of three studies. Loadings from northern Idaho and western Montana increased continuously with age. In Glacier National Park (Jeske and Bevins 1979), loadings decreased until stands were about 100 years old, then they increased. In the Selway-Bitterroot Wilderness, Idaho,[4] the loading trend was the reverse of that in Glacier National Park. In lodgepole pine on the Colorado Front Range, Alexander (1979) found a wide scatter in loading and stand age.

Because considerable data existed for the subalpine fir cover type, they were sorted by groups of two adjacent National Forests and loading patterns examined. The inconsistency in successional patterns is illustrated by the three loading trends observed for subalpine fir (fig. 9). The Flathead-Kootenai and Colville-Idaho Panhandle National Forests displayed similar trends. Loadings were high during the juvenile period, dropped during the immature and early maturity periods, and rose to a relatively high level maintained during the late maturity and overmature periods. This pattern is probably the most commonly encountered in forest types that begin after a high-intensity fire or insect epidemic causing high mortality.

High loadings during the juvenile period are caused by downfall of dead trees from the previous stand. Considerable time may be required for trees from the previous stand to decay and settle into the forest floor. In the event of another fire occurring during the juvenile period and consuming most of the downfall, the next stand will have much smaller downed fuel loadings during the juvenile period.

The commonly held notion that fuel quantities accumulate with age is, in many cases, untrue. Fuel succession is a complex process of many interacting factors. The generalization that fuels accumulate with time is an oversimplification. Two consistencies in fuel succession proposed for lodgepole pine (Brown 1975) seem to hold for all cover types: (1) fuel quantities become predictably high as stands become overmature, and (2) fuel quantities cannot be predicted from age alone in young, immature or mature stands. These consistencies are probably invalid for intensively managed stands where downed fuel quantities are controlled by cutting and removal activities.

In some vegetation communities, growth of understory vegetation such as young conifers can add substantially to fuel loadings and fire behavior potential. Fuel succession is more complicated when both living and dead fuels are involved because living fuels may increase while dead fuels decrease and conversely. When both dead and living fuels accumulate together, fire behavior potential can become excessively high. This probably occurs most frequently in overmature stands. Fuel characteristics are constantly changing to either increase or reduce flammability. Generalizations about fuel accumulation should be regarded with circumspection.

[4]Bevins, Collin D. 1977. Natural fuels accumulation in lodgepole pine. Unpub. rep. on file with "Systems for Environmental Management," Missoula, Mont.

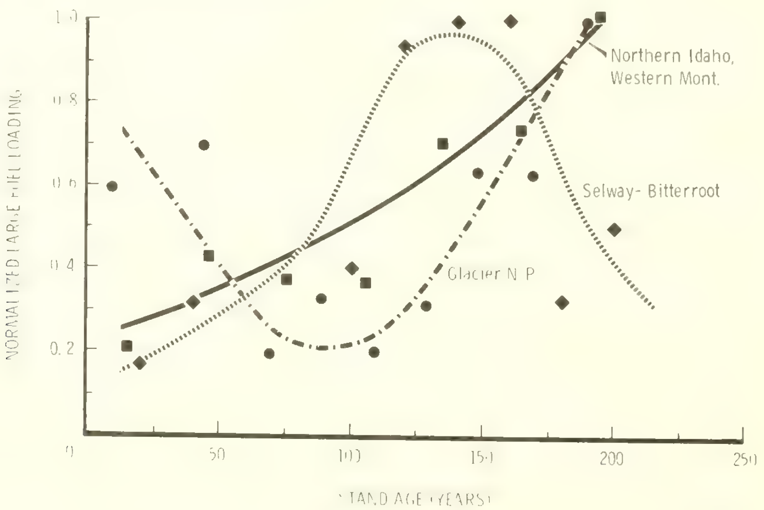

Figure 8. — Normalized loading of large downed woody fuel in lodgepole pine stands of varying age from three studies.

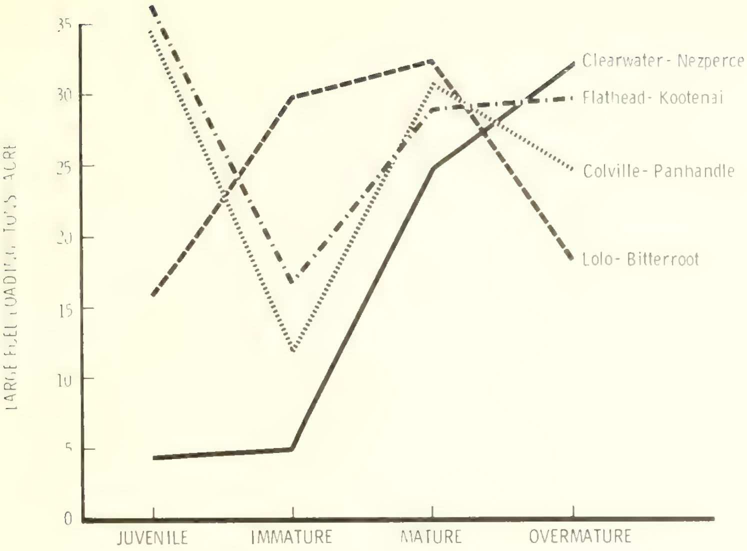

Figure 9. — Loading of large downed woody material in the subalpine fir cover type related to stand chronology. Juvenile encompasses stand ages of 0 to 50 years; immature, 51 to 100 years; mature, 101 to 150 years; and overmature, greater than 150 years.

Loading Versus Productivity

Loading generally increases with productivity as is shown in figures 10 and 11. The increasing trends probably exist because more productive sites grow more woody biomass for accumulation as downed woody fuel.

Unfortunately, the scatter of points in figures 10 and 11 indicates that accuracy in predicting loading from productivity would be poor. The scatter of points is probably due partly to fortuitous mortality events and random variation in the sample. Decay rates of wood and fire frequency may also explain some of the scatter. For example, loadings of some cold, dry site habitat types having relatively low productivities are similar to warm, moist site habitat types having relatively high productivities. Perhaps the net accumulation of fuel from the processes of accretion and decay is similar on the contrasting sites because lower decay rates on cold, dry sites offset the greater productivities on warmer, moist sites.

Historical fire frequency may account for differences in loadings among some habitat types of similar productivity. For example, *Abies lasiocarpa/Oplopanax horridum* and *Thuja plicata/Oplopanax horridum* habitat types have very high loadings (fig. 10). These moist sites are infrequently visited by fire leaving decay as the only process for reducing fallen trees to nonwoody compounds. Other habitat types of similar productivities, such as *Abies grandis/Clintonia uniflora* and *Thuja/Clintonia*, have less downed woody fuel perhaps because more frequently repeated fires have helped eliminate accumulated biomass. If effective fire control of the past 40 years is continued into the future, eventually fire frequency will cease to be a factor in causing different fuel accumulations.

Loading Versus Elevation and Aspect

We analyzed large fuel loadings for data stratified by aspect within elevation zones within cover types. Aspects were grouped into two categories, warm (SE, S, SW, W) and cool (NW, N, NE, E). Elevation was grouped into 1,000-ft zones. This analysis was repeated for groups of two National Forests and by Eastside and Westside National Forests.

For the two-Forest groups, loadings differed among some elevations and aspects; the differences, however, were inconsistent among cover types and Forests. The inconsistency together with limited data precluded drawing conclusions about elevation and aspect on a two-Forest basis. For the Westside and Eastside Forests, the data was substantial. Results showed that differences in loadings between elevations and between aspects were mostly small and lacked an explainable pattern (table 6). Thus, prediction of loadings from aspect and elevation seemed unwarranted. A few interesting trends were suggested, however. For example, on Eastside Forests, loadings of Douglas-fir were less below 6,000 ft (1 829 m) than above this elevation, whereas on Westside Forests, loadings of Douglas-fir fell off above 6,000 ft (fig. 12). Loadings in Westside Douglas-fir above 6,000 ft may fall off because at this elevation it is a marginal species with restricted productivity. Loadings of lodgepole pine were greater on north than south aspects, but real differences in loadings due to elevation were not apparent. For the larch-grand fir cover type, loading showed an increasing trend with elevation. For cedar-hemlock, loading was maximum at 4,000 to 5,000 ft (1 219 to 1 524 m) with smaller loadings above and below that elevation (table 6).

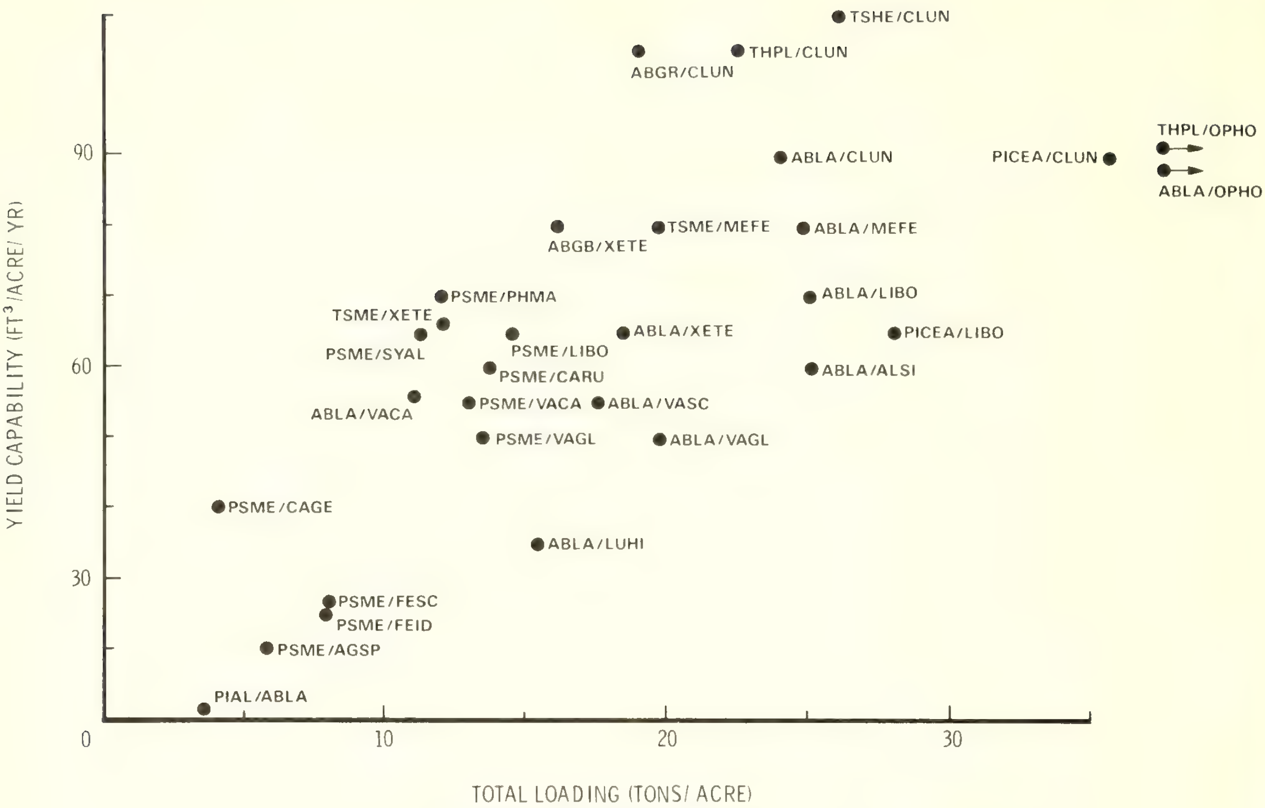

Figure 10. — Ordination of habitat types by yield capability and total downed woody fuel loading for Westside Forests. Yield capabilities are from Pfister and others (1977). Plotted habitat types are represented by at least 5 stands or 35 sample points.

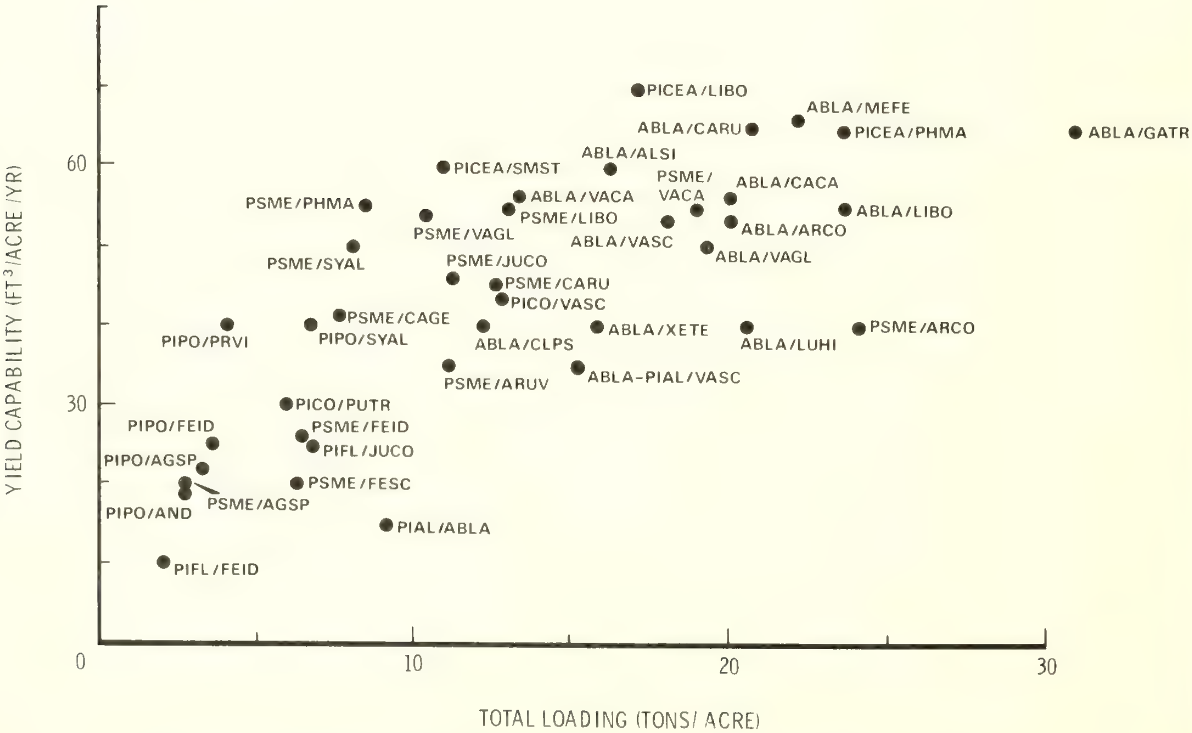

Figure 11. — Ordination of habitat types by yield capability and total downed woody fuel loading for Eastside Forests. Yield capabilities are from Pfister and others (1977). Plotted habitat types are represented by at least five stands or 35 sample points.

Table 6.—Weighted mean loadings of large downed woody material for northerly and southerly aspects within 1,000-ft elevation bands by cover type. Number of sample stands is shown in parentheses

Cover type[1]	Elevation (feet) and aspect (north or south)									
	3,000-3,900		4,000-4,900		5,000-5,900		6,000-6,900		7,000-7,900	
	N	S	N	S	N	S	N	S	N	S
	Tons/acre									
	Westside National Forests									
DF	11.2 (138)	12.1 (305)	15.3 (178)	9.2 (165)	13.5 (150)	12.7 (157)	7.6 (63)	7.4 (58)		
LP	16.6 (20)	11.4 (47)	18.2 (202)	10.4 (94)	14.7 (122)	12.4 (145)	13.3 (71)	11.9 (44)		
S-F			29.2 (56)	20.9 (43)	23.9 (220)	34.4 (101)	20.5 (163)	21.7 (50)		
L	15.0 (164)	11.8 (212)	15.4 (224)	16.5 (127)	22.5 (92)	18.2 (44)				
C-H	29.5 (39)	21.8 (78)	32.4 (93)	34.9 (41)	20.4 (31)	15.8 (32)				
	Eastside National Forests									
DF					7.3 (64)	6.5 (64)	9.3 (114)	9.0 (150)	13.4 (70)	10.0 (39)
LP					8.9 (27)	9.1 (15)	13.2 (138)	10.7 (99)	14.2 (177)	12.4 (114)

[1]DF = Douglas-fir.
LP = Lodgepole pine.
S-F = Engelmann spruce-subalpine fir.
L = Western larch-grand fir.
C-H = Western redcedar-western hemlock.

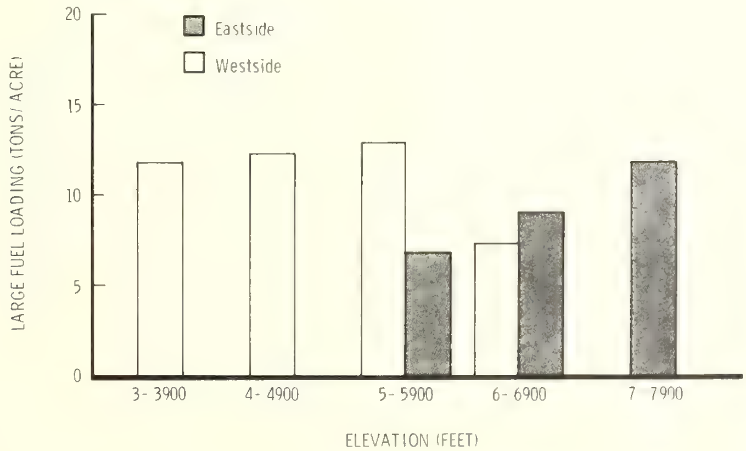

Figure 12. — Large fuel loadings averaged for 1,000-ft elevation zones in the Douglas-fir cover type on Eastside and Westside National Forests.

Accumulation of downed woody material might be expected to relate to elevation and aspect because of differences in rates of decay and productivity. However, because many factors, such as cover type and stand history, also account for accumulations of downed woody material, isolating the influence of elevation and aspect was difficult. Extensive data were required to evaluate influences of elevation and aspect on fuel loading. Where data permitted a reasonably confident analysis, the influences of elevation and aspect on loading were rather small. Factors accounting for the influences remain in question, but probably relate to causes of tree mortality.

Duff depth was significantly greater on cool than on warm aspects in ponderosa pine and to a lesser extent in cedar-hemlock (table 7). Duff depth, however, did not vary significantly between aspects for other cover types as was observed by Alexander (1979) for lodgepole pine in Colorado. The difference in duff depths between aspects in ponderosa pine may be due mostly to lower stocking and litter fall on southerly exposures. Aspect was suspected of influencing duff depth because decay was expected to progress more slowly on cool sites. The data suggest, but do not confirm it.

Photo Interpretation of Loading

The possibility of using aerial photography to determine fuel loadings was investigated using the Northern Region Photo Interpretation Classification (Stage and Alley 1972). Eight photo interpretation groups were formed from the Region's larger PI Classification. Region 1's codes for these groups are shown in appendix VII.

Group means weighted by number of plots and a Scheffe's multiple comparison test at the 90 percent confidence level indicate that little discrimination among photo interpretation (PI) classes is warranted (table 8). On the Westside, the following three PI class groups appear justified for interpreting loadings based on the similarity of means and tests of differences:

PI class	**Loadings**	
	Large fuel	**Small fuel**
	Tons/acre	
Stands poorly stocked	9.1	2.4
Stands medium and well stocked	16.4	3.1
Cutover stands	22.8	3.9

On the Eastside, analysis suggests that PI class is of no value for estimating loading. The bulk of the data represented medium- and well-stocked pole and sawtimber stands, which for large fuels averaged about 12 tons/acre (2.7 kg/m^2). Loadings of the other groups displayed an ambiguous pattern.

Loadings of the PI groups were not normally distributed. Thus, the results of Scheffe's tests are inexact, but still of interest with cautious interpretation. Because of highly variable loadings, PI class can be used appropriately only for broad coverage groups such as tabulated for the Westside.

Table 7.—Average duff depths on warm and cool aspects in Westside National Forests

Aspect	**Cover type[1]**					
	LP	**S-F**	**L**	**DF**	**C-H**	**PP**
	Inches					
Warm	1.13	1.42	1.15	0.86	1.36	0.51
Cool	1.13	1.44	1.23	.94	1.57	.97
Difference	0	.02	.08	.08	.21	.46

[1]LP = Lodgepole pine.
S-F = Engelmann spruce-subalpine fir.
L = Western larch-grand fir.
DF = Douglas-fir.
C-H = Western redcedar-western hemlock.
PP = Ponderosa pine.

Table 8.—Mean loadings for photo interpretation groups on Westside and Eastside National Forests. The vertical lines connect groups whose means are nonsignificantly different

Group number[1]	PI class	Number of plots	Large material	Small material
			Tons acre	
	Westside			
6	Under 40, poor	354	8.2	2.4
3	Over 40, poor	559	9.7	2.4
2	Over 40, medium and well, pole	6,718	15.0	3.1
1	Over 40, medium and well, saw	4,094	17.3	3.1
5	Under 40, medium and well	653	17.7	3.2
4	Over 40, two-storied	4,378	17.7	3.0
8	Cutover, poor	1,535	20.9	3.7
7	Cutover, medium and well	1,748	24.4	4.1
	Eastside			
3	Over 40, poor	435	5.8	1.2
1	Over 40, medium and well, saw	4,745	11.6	2.3
2	Over 40, medium and well, pole	1,676	12.9	2.4
7	Cutover, medium and well	147	13.6	3.1
5	Under 40, medium and well	366	13.6	2.1
8	Cutover, poor	232	17.1	3.4
6	Under 40, poor	36	18.6	3.7
4	Over 40, two-storied	244	18.7	3.0

[1]1 = Limber pine (*Pinus flexilis*); ponderosa pine, and Douglas-fir bunch grass types.
2 = Dry site Douglas-fir and moist site ponderosa pine.
3 = Moist site Douglas-fir
4 = Cool sites dominated by lodgepole pine; dry, lower elevation subalpine fir.
5 = Moist site, lower elevation subalpine fir
6 = Cold, moist site upper elevation subalpine fir.
7 = Warm, moist sites; mostly cedar-hemlock.

FIRE MANAGEMENT APPLICATIONS

Estimates of fuel loadings and fire behavior can help in planning at all administrative levels and in conducting presuppression, suppression, and prescribed fire activities. Besides downed woody material, fuels such as litter, grasses, forbs, and shrubs are often essential in appraising fire potential. However, knowledge of downed woody material alone can be useful because within given forest communities, it can vary substantially while loadings of herbaceous vegetation and litter remain more uniform. Thus, assuming topography and weather are constant, differences in fire behavior among stands from the same forest community type are most likely due to differences in loading of downed woody material especially on mesic and wet sites.

Some specific applications might include:

1. Decisions can be made as to whether or not fuel inventory is necessary on areas planned for harvesting. If large fuel loadings are expected from harvesting, inventory of existing fuels may be desirable; but, if small loadings are expected, inventory is likely to be unnecessary. Slash fuel hazard can be appraised using procedures described by Puckett and others (1979). These procedures require estimates of fuel loadings existing before cutting. Although loading estimates summarized here are less accurate than provided by inventory, they might be used where inventory is impractical.

2. Loading summaries could be used to help select proper fuel models for operating the National Fire-Danger Rating System (Deeming and others 1977) and estimating wildfire behavior using nomographs (Albini 1976). In both cases, users must sometimes select between fuel models for forests having only a nominal loading of downed woody fuel and forests having a heavy accumulation of downed fuel. Depending upon the accuracy required in applying fire-danger ratings or fire behavior estimates, average loadings by broadly defined vegetation types can help in selecting between fuel models having nominal and heavy loadings.

3. Loading summaries are appropriate for fuel and fire management planning requiring low resolution fuel information. Loading information alone can be useful for appraising problems of fuels greater than 3 inches in diameter. Fire behavior potentials of large fuels are inadequately appraised when only rate of fire spread and intensity are considered. Although large fuels contribute to flame front advance, they probably present more difficulties to land managers because of their prolonged burnout time. This can lead to undesirable fire effects. Fire suppression in large fuels is arduous and expensive. Large fires easily occur in accumulations of large fuels because sustained burning and smoldering create prolonged ignition sources that high winds can readily fan into fast moving fires. Although interpretation of large fuel problems requires considerable judgment, knowledge of loadings provides an objective foundation on which to evaluate fire behavior potentials.

SUMMARY AND CONCLUSIONS

Weights and volumes of downed woody biomass and fuel in diameter classes of one-fourth to 1 inch (0.6 to 2.5 cm), 1 to 3 inches (2.5 to 7.6 cm), and greater than 3 inches (7.6 cm) and of forest floor duff depths were summarized from extensive inventories in northern Idaho and Montana. Quantities of downed woody material varied more among cover types than among habitat types because cover types reflect the tree species comprising most of the downed woody material.

Total, downed woody biomass east of the Continental Divide ranged from 5 tons/acre (11.2 t/ha) in the ponderosa pine cover type to 23 tons/acre (51.6 t/ha) in the spruce-fir. West of the Divide, loadings ranged from 13 tons/acre (29.2 t/ha) in ponderosa pine to 33 tons/acre (74.0 t/ha) in cedar-hemlock. Duff depths for cover types ranged from 0.5 to 1.5 inches (1.3 to 3.8 cm). Westside Forests displayed greater loadings and larger piece diameters than Eastside Forests probably because productivities and tree sizes average greater on the Westside.

High-risk stands contained up to three times as much as the average downed woody biomass on individual National Forests. Assuming that 10 tons/acre (22.4 t/ha) of downed woody biomass greater than 3 inches (7.6 cm) in diameter should be retained on site, the greatest excess quantities per acre occurred in the cedar-hemlock and spruce-fir cover types. The only cover type not showing an excess was ponderosa pine.

The data were highly variable and skewed strongly to the right, indicating that downed woody material tends to occur in scattered concentrations rather than in uniform distributions. Correlations between loadings of different size classes were poor. Thus, loadings of one size class cannot be predicted with reasonable precision from loadings of another size class.

On Westside Forests, photo interpretation classes representing (1) stands poorly stocked, (2) stands medium- and well-stocked, and (3) cutover areas discriminated significantly different large fuel loadings. On Eastside Forests, PI classes were unable to distinguish significantly different loadings.

Cover type and habitat type group averages provided the most meaningful estimation of loadings. Loadings generally increased with productivity, presumably because more productive sites grow more biomass that eventually falls to the ground in the absence of utilization. Regression analysis failed to produce reliable relationships between the dependent variables of duff depth and downed woody material and the independent variables of stand age, slope, aspect, and elevation ($R^2 = 0.05$ to 0.15).

The lack of substantive relationships between downed biomass loadings and stand age is probably due to several factors including high variability in loadings among stands. More importantly, tree mortality and downfall can occur at all stand ages. The relationship between biomass accumulations and stand age is ambiguous because the origin of stands was often unclear. Most stands contained a wide range of tree ages.

Biomass accumulates with time, but the generalization that fuels accumulate with time is replete with exceptions. This study and review of others indicate that downed woody fuel quantities tend to become predictably high as stands become overmature, but unpredictable from age alone in young immature and mature stands. Generalizations about fuel accumulation should be interpreted and applied cautiously.

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APPENDIX I

Forest Inventory Fuel Summaries by National Forest

Loadings of downed woody material and duff depths are summarized by National Forest and cover type in table 9 and by habitat type groups in table 10. Cover types known to occur on a National Forest, but not shown in the tables were represented by too little data to warrant analysis. The western white pine cover type was almost included, but it occurred with only marginally acceptable data on two National Forests. To qualify for summary in the tables, at least 10 stands or 75 sample points were required. Number of sample points is shown only with the 0.25- to 1-inch (0.6- to 2.5-cm) category; it is the same for all other categories within a National Forest.

Duff depth shown in the tables can be a useful expressionof duff quantity. However, if duff loading is desired for some purposes, it can be computed by knowing bulk density. Duff bulk density is known to vary from 4.7 lb/ft^3 (0.075 g/cm^3) in ponderosa pine stands (Brown 1970) to 11.2 lb/ft^3 (0.18 g/cm^3) in western hemlock and Douglas-fir stands (Mader 1953). In lodgepole pine stands, it averaged 8.7 lb/ft^3 (0.14 g/cm^3) (Brown 1974b). Assuming a bulk density of 8 lb/ft^3 (0.13 g/cm^3), loading in tons per acre can be calculated as 14.5 times duff depth in inches. Assuming a bulk density of 5.5 lb/ft^3 (0.088 g/cm^3), suitable for ponderosa pine, loading in tons per acre can be calculated as 10 times duff depth in inches. Unless measured bulk densities are available, these expressions provide rough approximations of duff loadings for most forest types.

Table 9. — Loadings of downed woody material and depths of forest floor duff by National Forest and cover type from Forest Survey data

Fuel category	Cover type	Mean	Standard deviation	First quartile	Median	Third quartile	Number points
		Tons/acre					
		Bitterroot National Forest					
	PP	0.4	0.8	0	0	0.5	218
	DF	.5	.8	0	0	.8	1,056
¼ to 1 inch	LP	.4	.6	0	0	.5	203
	S-F	.6	1.0	0	0	.9	156
	All	.5	.8	0	0	.8	1,633
	PP	1.0	2.7	0	0	0	
	DF	1.2	2.8	0	0	2.1	
1 to 3 inch	LP	1.1	2.2	0	0	2.1	
	S-F	1.3	2.4	0	0	2.1	
	All	1.1	2.7	0	0	2.1	
	PP	5.3	14.0	0	0	1.5	
	DF	9.2	18.7	0	0	10.6	
Large	LP	12.2	19.8	0	0	17.2	
	S-F	16.1	24.9	0	5.3	22.9	
	All	9.7	19.1	0	0	11.0	
	PP	7	15	0	0	4	
	DF	11	20	0	1	14	
Total woody material	LP	14	21	0	2	19	
	S-F	18	27	0	8	28	
	All	11	20	0	.8	14.6	
		Inches					
	PP	0.4	1.0	0	0	0.2	
	DF	.5	.8	0	0	.6	
Duff depth	LP	.5	.9	0	0	.6	
	S-F	.8	1.7	0	0	.9	
	All	.5	1.0	0	0	.6	
		Tons/Acre					
		Clearwater National Forest					
	DF	1.4	1.2	0.6	1.0	1.9	520
	LP	1.0	1.1	0	.6	1.4	458
¼ to 1 inch	L	1.5	1.3	.5	1.2	2.2	517
	S-F	.9	1.1	0	.6	1.3	453
	C-H	1.4	1.3	.6	1.0	2.0	501
	All	1.2	1.2	.3	.9	1.7	2,449
	DF	3.3	5.1	0	2.2	4.9	
	LP	1.4	3.6	0	0	2.2	
1 to 3 inch	L	3.1	5.1	0	0	4.6	
	S-F	1.9	3.7	0	0	2.3	
	C-H	3.2	5.4	0	2.1	4.8	
	All	2.6	4.8	0	0	2.7	
	DF	15.9	29.3	0	0	19.8	
	LP	7.3	18.8	0	0	4.4	
Large	L	19.4	32.6	0	3.1	26.7	
	S-F	14.6	35.1	0	0	16.5	
	C-H	24.3	31.9	0	12.3	34.4	
	All	16.5	30.6	0	1.6	21.5	
	DF	21	30	2	8	26	
	LP	10	20	0	2	10	
Total woody material	L	24	34	2	10	33	
	S-F	17	36	1	5	21	
	C-H	29	33	5	19	40	
	All	20	32	1	7	27	
		Inches					
	DF	0.9	1.3	0	0.3	1.1	
	LP	.5	1.0	0	.1	.6	
Duff depth	L	1.1	1.4	0	.6	1.6	
	S-F	.9	1.5	0	.3	1.2	
	C-H	1.3	1.7	.2	.6	1.7	
	All	.9	1.4	0	.3	1.3	

(Con.)

Table 9. — (Con.)

Fuel category	Cover type	Mean	Standard deviation	First quartile	Median	Third quartile	Number points
		Tons/acre					
		Colville National Forest					
	PP	1.1	1.2	0.2	0.6	1.4	196
	DF	1.3	1.3	.3	.8	1.9	528
¼ to 1 inch	LP	1.4	1.2	.5	1.1	2.1	310
	L	1.5	1.3	.5	1.1	2.2	1,838
	S-F	1.3	1.2	.3	.9	1.8	245
	C-H	1.6	1.2	.6	1.2	2.3	249
	All	1.4	1.3	.3	1.1	2.2	3,366
	PP	2.7	5.6	0	0	3.4	
	DF	2.5	4.0	0	0	4.3	
1 to 3 inch	LP	3.1	5.1	0	2.1	4.4	
	L	2.8	4.2	0	2.1	4.4	
	S-F	3.2	4.7	0	2.2	4.5	
	C-H	3.6	4.6	0	2.2	4.6	
	All	2.8	4.5	0	2.1	4.4	
	PP	22.8	34.2	0	5.3	34.2	
	DF	15.1	27.9	0	3.1	18.1	
Large	LP	19.1	25.9	0	8.0	27.2	
	L	17.0	26.0	0	6.4	22.4	
	S-F	38.4	41.3	6.7	28.8	54.3	
	C-H	41.1	53.1	4.8	24.6	53.6	
	All	20.6	32.0	0	7.9	28.7	
	PP	27	36	1	11	39	
	DF	19	29	1	8	25	
Total woody material	LP	24	15	4	14	35	
	L	21	27	3	12	29	
	S-F	43	42	12	34	59	
	C-H	46	54	11	31	62	
	All	25	33	4	13	34	
		Inches					
	PP	0.6	0.8	0	0.3	0.8	
	DF	.7	1.0	0	.3	1.0	
Duff depth	LP	1.0	1.1	.3	.8	1.4	
	L	1.1	1.2	.2	.8	1.5	
	S-F	1.5	1.6	.3	1.1	2.0	
	C-H	1.8	1.8	.5	1.3	2.8	
	All	1.1	1.3	.2	.7	1.5	
		Tons/acre					
		Deerlodge National Forest					
	DF	0.8	0.9	0	0.5	1.1	981
	LP	.7	.8	0	.5	.8	1,347
¼ to 1 inch	S-F	.8	1.0	0	.5	1.1	279
	All	.7	.9	0	.5	1.1	2,607
	DF	1.7	3.1	0	0	2.2	
	LP	1.6	2.7	0	0	2.2	
1 to 3 inch	S-F	1.7	3.1	0	0	2.2	
	All	1.7	2.9	0	0	2.2	
	DF	10.6	18.9	0	2.2	13.9	
	LP	15.8	27.8	0	7.5	21.9	
Large	S-F	20.4	25.2	0	11.0	30.6	
	All	14.4	24.7	0	5.6	19.9	
	DF	13	20	1	6	18	
	LP	18	28	2	10	25	
Total woody material	S-F	23	26	3	13	35	
	All	17	25	1	8	23	
		Inches					
	DF	1.1	1.1	0.3	.8	1.6	
	LP	1.3	1.3	.3	1.0	2.0	
Duff depth	S-F	1.5	1.6	.4	1.1	2.2	
	All	1.3	1.3	.3	1.0	1.8	

(Con.)

Table 9. — (Con.)

Fuel category	Cover type	Mean	Standard deviation	First quartile	Median	Third quartile	Number points
		Tons acre					
		Flathead National Forest					
	DF	1.0	1.0	0.3	0.8	1.4	668
	LP	1.0	1.1	.3	.7	1.4	625
¼ to 1 inch	L	.9	.9	.3	.6	1.3	469
	S-F	1.1	1.1	.3	.8	1.6	690
	All	1.0	1.1	.3	.8	1.4	2,452
	DF	1.8	3.4	0	0	2.3	
	LP	2.6	4.3	0	0	2.5	
1 to inch	L	1.8	2.9	0	0	2.2	
	S-F	1.7	3.1	0	0	2.2	
	All	2.0	3.5	0	0	2.3	
	DF	17.0	26.6	0	6.4	23.1	
	LP	18.7	25.2	0	9.0	26.8	
Large	L	18.1	25.9	0	8.4	25.7	
	S-F	28.6	39.7	2.7	16.7	41.8	
	All	20.9	30.8	0	10.0	29.3	
	DF	20	28	2	9	27	
	LP	22	26	3	13	33	
Total woody material	L	21	26	3	11	28	
	S-F	31	40	4	20	44	
	All	24	32	3	13	34	
		Inches					
	DF	1.3	1.5	0.3	0.9	1.8	
	LP	1.3	1.3	.4	1.0	1.8	
Duff depth	L	1.5	1.5	.5	1.1	1.9	
	S-F	2.0	1.9	.6	1.6	2.9	
	All	1.5	1.6	.4	1.1	2.1	
		Tons/acre					
		Gallatin National Forest					
	DF	0.9	1.0	0.3	0.7	1.4	533
	LP	.9	.9	.3	.6	1.1	624
¼ to 1 inch	S-F	.9	1.0	0	.6	1.4	301
	All	.9	1.0	.3	.6	1.2	1,458
	DF	1.8	4.3	0	0	2.2	
	LP	1.9	3.3	0	0	2.2	
1 to 3 inch	S-F	1.7	2.7	0	0	2.2	
	All	1.8	3.6	0	0	2.2	
	DF	10.2	23.1	0	1.2	11.5	
	LP	18.1	35.7	0	6.4	24.7	
Large	S-F	19.6	30.2	0	9.2	24.7	
	All	15.5	30.7	0	4.4	19.8	
	DF	13	26	1	4	15	
	LP	21	37	2	9	29	
Total woody material	S-F	22	31	1	13	29	
	All	18	32	1	7	24	
		Inches					
	DF	1.1	1.3	0.3	0.8	1.6	
	LP	1.1	1.1	.3	.7	1.5	
Duff depth	S-F	1.2	1.6	.2	.7	1.8	
	All	1.1	1.3	.2	.7	1.6	

(Con.)

Table 9. — (Con.)

Fuel category	Cover type	Mean	Standard deviation	First quartile	Median	Third quartile	Number points
		Tons/acre					
		Helena National Forest					
	PP	0.5	0.7	0	0	0.6	184
	DF	.8	1.0	0	.3	1.1	961
¼ to 1 inch	LP	.6	.7	0	.3	.9	1,429
	S-F	.8	.9	.3	.5	1.1	132
	All	.7	.8	0	.3	1.1	2,706
	PP	.6	1.8	0	0	0	
	DF	1.3	2.5	0	0	2.1	
1 to 3 inch	LP	1.3	2.4	0	0	2.1	
	S-F	2.1	4.0	0	0	2.3	
	All	1.3	2.5	0	0	2.1	
	PP	3.9	16.1	0	0	1.2	
	DF	8.3	18.0	0	0	8.4	
Large	LP	10.4	19.3	0	2.3	13.0	
	S-F	21.3	22.1	4.5	15.7	32.8	
	All	9.7	19.0	0	1.3	11.4	
	PP	5	16	0	1	4	
	DF	10	19	0	3	12	
Total woody material	LP	12	20	1	5	15	
	S-F	24	23	6	17	38	
	All	12	20	0	4	14	
		Inches					
	PP	0.6	0.8	0	0.3	0.9	
	DF	.8	.9	0	.4	1.3	
Duff depth	LP	.9	1.1	.1	.6	1.3	
	S-F	1.3	1.6	.2	.8	1.8	
	All	.9	1.1	.1	.5	1.3	
		Tons/acre					
		Kaniksu National Forest					
	DF	1.4	1.1	0.5	1.1	2.1	99
	LP	1.2	1.0	.5	.9	1.7	99
¼ to 1 inch	L	1.0	1.1	0	.8	1.6	756
	S-F	1.1	1.1	.3	.8	1.5	498
	C-H	1.0	1.0	.3	.8	1.4	443
	All	1.1	1.1	0	.8	1.6	1,895
	DF	1.8	2.7	0	0	2.2	
	LP	2.5	4.0	0	0	4.3	
1 to 3 inch	L	1.7	3.0	0	0	2.2	
	S-F	1.9	3.2	0	0	2.2	
	C-H	1.9	3.2	0	0	2.2	
	All	1.9	3.4	0	0	2.2	
	DF	21.8	29.6	0	10.4	33.2	
	LP	13.8	24.2	0	3.1	14.8	
Large	L	24.6	34.9	0	9.0	36.4	
	S-F	24.5	34.6	0	10.5	36.4	
	C-H	25.7	33.9	1.2	13.1	38.1	
	All	20.8	36.9	0	6.2	27.8	
	DF	25	30	3	13	34	
	LP	18	25	2	8	21	
Total woody material	L	27	35	3	13	39	
	S-F	27	36	3	14	39	
	C-H	29	35	4	16	41	
	All	24	38	2	10	31	
		Inches					
	DF	1.5	1.5	0.4	1.0	2.2	
	LP	2.1	2.6	.5	1.0	2.3	
Duff depth	L	1.3	1.6	.2	.8	1.8	
	S-F	1.3	1.6	.3	.8	1.8	
	C-H	1.3	1.6	.3	.8	1.8	
	All	1.3	1.7	.1	.8	1.8	

(Con.)

Table 9. — (Con.)

Fuel category	Cover type	Mean	Standard deviation	First quartile	Median	Third quartile	Number points
				Tons acre			
			Kootenai National Forest				
	PP	0.5	0.8	0	0.3	0.8	150
	DF	1.1	1.2	.3	.8	1.6	960
	LP	1.0	1.1	.3	6	1.4	1,061
¼ to 1 inch	L	1.1	1.1	.3	8	1.6	765
	S-F	.9	1.0	0	5	1.4	393
	C-H	1.3	1.2	3	9	1.9	271
	All	1.0	1.1	.3	6	1.4	3,600
	PP	1.4	2.7	0	0	2.1	
	DF	1.9	3.4	0	0	2.4	
	LP	2.1	3.3	0	0	2.5	
1 to 3 inch	L	2.2	3.6	0	0	2.5	
	S-F	2.0	3.3	0	0	2.4	
	C-H	2.2	3.7	0	0	2.6	
	All	2.0	3.4	0	0	2.4	
	PP	5.9	19.6	0	0	2.8	
	DF	10.9	22.2	0	1.6	13.7	
	LP	14.4	26.3	0	4.3	18.1	
Large	L	20.8	31.6	0	9.3	27.6	
	S-F	26.0	46.2	0	6.8	33.2	
	C-H	35.6	64.3	0	13.3	44.6	
	All	17.3	34.1	0	4.4	21.0	
	PP	8	20	0	1	7	
	DF	14	23	1	5	17	
	LP	17	27	2	8	22	
Total woody material	L	24	32	4	13	33	
	S-F	29	47	2	11	36	
	C-H	39	65	4	17	49	
	All	20	35	2	8	25	
				Inches			
	PP	0.9	1.2	0	0.5	1.5	
	DF	1.3	1.4	.3	1.0	1.8	
	LP	1.5	1.6	.4	1.1	2.0	
Duff Depth	L	1.7	1.6	6	1.4	2.3	
	S-F	1.6	2.1	0	.9	2.5	
	C-H	2.2	2.5	.5	1.5	2.9	
	All	1.5	1.7	.3	1.1	2.1	
				Tons/acre			
			Lolo National Forest				
	PP	0.9	1.1	0	0.5	1.7	120
	DF	1.2	1.4	.3	.9	1.7	1,000
	LP	1.1	1.1	.3	8	1.6	768
¼ to 1 inch	L	1.4	1.4	.5	9	2.1	176
	S-F	1.0	1.1	3	.6	1.4	837
	C-H	1.4	1.2	.3	1.3	1.9	49
	All	1.1	1.2	3	.8	1.6	2,950
	PP	1.3	2.6	0	0	2.2	
	DF	1.4	2.9	0	0	2.3	
	LP	2.4	3.7	0	0	2.6	
1 to 3 inch	L	1.9	2.8	0	0	2.4	
	S-F	1.6	2.9	0	0	2.3	
	C-H	1.6	2.2	0	0	2.4	
	All	1.8	3.1	0	0	2.4	
	PP	4.8	15.8	0	0	1.9	
	DF	11.5	23.1	0	1.3	13.2	
	LP	13.3	21.8	0	3.5	17.6	
Large	L	16.9	34.6	0	6.4	18.2	
	S-F	21.0	38.3	0	6.7	28.8	
	C-H	17.9	31.7	0	2.1	19.1	
	All	14.8	28.9	0	3.0	18.5	
	PP	7	16	0	2	7	
	DF	14	24	1	4	18	
	LP	17	23	2	8	22	
Total woody material	L	20	35	4	10	24	
	S-F	24	39	2	11	32	
	C-H	21	33	2	6	21	
	All	18	30	1	7	22	
				Inches			
	PP	0.5	0.6	0	0.3	0.8	
	DF	1.1	1.4	.3	8	1.4	
	LP	1.2	1.2	.3	9	1.8	
Duff depth	L	1.5	1.5	.4	1.3	1.9	
	S-F	1.3	1.5	.2	9	1.9	
	C-H	1.2	1.5	0	8	1.5	
	All	1.2	1.3	.3	8	1.6	

(Con.)

Table 9. — (Con.

Fuel category	Cover type	Mean	Standard deviation	First quartile	Median	Third quartile	Number points
			Tons acre				
			Nezperce National Forest				
	PP	1.1	1.3	0	0.7	1.5	257
	DF	1.1	1.1	.3	.9	1.6	611
	LP	.8	.9	0	.6	1.2	499
¼ to 1 inch	L	1.2	1.2	.3	.9	1.7	639
	S-F	.8	1.0	0	.5	1.1	189
	C-H	1.8	1.3	.8	1.6	2.3	75
	All	1.1	1.1	.3	8	1.6	2,270
	PP	1.4	2.8	0	0	2.4	
	DF	1.9	3.4	0	0	2.6	
	LP	1.7	3.0	0	0	2.3	
1 to 3 inch	L	1 8	3.2	0	0	2.3	
	S-F	1.7	3.5	0	0	2.2	
	C-H	3.2	3.3	0	2.4	4.6	
	All	1.8	3.2	0	0	2.4	
	PP	10.7	20.9	0	0	12.9	
	DF	14.5	29.3	0	1.4	17.6	
	LP	14.8	26.0	0	4.9	19.2	
Large	L	22.1	34.8	0	5.5	32.4	
	S-F	17.7	27,5	0	4.2	26.2	
	C-H	22.9	29.9	1.6	9.6	33	
	All	16.8	29.6	0	3.1	21.9	
	PP	13	22	0	3	17	
	DF	18	30	1	5	22	
	LP	17	27	1	9	22	
Total woody material	L	25	36	1	9	36	
	S-F	20	29	0	7	28	
	C-H	28	30	8	17	40	
	All	20	31	1	7	26	
			Inches				
	PP	0.6	1.3	0	0.2	.7	
	DF	7	1.1	0	.3	.9	
	LP	6	.9	0	.3	.8	
Duff depth	L	.8	1.0	.1	.5	1.1	
	S-F	9	1.4	0	.3	1.3	
	C-H	1 3	1.1	.6	1.0	2.0	
	All	7	1.1	0	4	1.0	
			Tons acre				
			St. Joe National Forest				
	DF	1.1	1.1	0.3	0.8	1.6	321
	LP	1 1	1.0	.3	.8	1.6	149
¼ to 1 inch	L	.8	1.0	0	.5	1.3	221
	S-F	1.0	1.2	0	.5	1.6	136
	C-H	.9	1.0	0	.5	1.6	139
	All	1.0	1.1	0	.8	1.6	966
	DF	1 8	2.9	0	0	2.1	
	LP	2.5	2.8	0	2.1	4.3	
1 to 3 inch	L	2.3	3.8	0	0	4.3	
	S-F	2.0	3.5	0	0	2.1	
	C-H	1.8	2.8	0	0	2.1	
	All	2.1	3.2	0	0	2.1	
	DF	11.9	26.0	0	0	13.0	
	LP	15.6	17.8	1.2	8.9	28.7	
Large	L	12.4	21.6	0	0	18.8	
	S-F	22.5	37.0	0	3.4	31.9	
	C-H	21.9	46.8	0	4.8	22.0	
	All	15.5	30.1	0	2.7	19.4	
	DF	15	27	1	5	17	
	LP	19	19	5	13	29	
Total woody material	L	15	23	0	6	23	
	S-F	26	38	0	10	36	
	C-H	25	48	0	9	31	
	All	19	31	1	7	25	
			Inches				
	DF	0.7	0.9	0	0.4	1.0	
	LP	.9	1.0	.2	.7	1.3	
Duff depth	L	.6	1.0	0	.2	.7	
	S-F	.6	1.1	0	.2	.7	
	C-H	.9	1.3	0	.4	1.5	
	All	.7	1.1	0	.4	1.0	

(Con.)

Table 9. — (Con.)

Fuel category	Cover type	Mean	Standard deviation	First quartile	Median	Third quartile	Number points
			Tons/Acre				
			Eastside Forests				
	PP	0.5	0.7	0	0	0.6	184
	DF	.8	.9	0	.5	1.1	2,475
¼ to 1 inch	LP	.7	.8	0	.5	.9	3,400
	S-F	.8	1.0	0	.5	1.2	712
	All	.7	.9	0	.5	1.1	6,771
	PP	.6	1.8	0	0	0	
	DF	1.6	3.2	0	0	2.2	
1 to 3 inch	LP	1.5	2.7	0	0	2.2	
	S-F	1.7	3.1	0	0	2.2	
	All	1.5	2.9	0	0	2.2	
	PP	3.9	16.1	0	0	1.2	
	DF	9.6	19.6	0	1.2	11.7	
Large	LP	13.9	26.6	0	4.7	18.2	
	S-F	20.2	26.9	0	11.2	29.0	
	All	12.8	24.3	0	3.3	16.8	
	PP	5	16	0	1	4	
	DF	12	21	1	4	15	
Total woody material	LP	16	27	1	7	22	
	S-F	23	28	2	14	33	
	All	15	25	1	6	20	
			Inches				
	PP	0.6	0.8	0	0.3	0.9	
	DF	1.0	1.1	.1	.7	1.5	
Duff depth	LP	1.1	1.2	.2	.8	1.6	
	S-F	1.3	1.6	.2	.9	1.9	
	All	1.1	1.2	.2	.7	1.6	
			Tons/acre				
			Westside Forests				
	PP	0.9	1.4	0	0.5	1.1	944
	DF	1.0	1.2	0	.7	1.6	5,762
	LP	1.0	1.1	.3	.6	1.4	4,172
¼ to 1 inch	L	1.3	1.2	.3	.9	1.9	5,381
	S-F	1.0	1.1	0	.6	1.4	3,597
	C-H	1.3	1.2	.3	1.0	1.9	1,727
	All	1.1	1.2	—	.8	—	21,584
	PP	1.6	3.9	0	0	2.2	
	DF	1.8	3.4	0	0	2.4	
	LP	2.1	3.7	0	0	2.4	
1 to 3 inch	L	2.3	3.8	0	0	2.7	
	S-F	1.9	3.3	0	0	2.3	
	C-H	2.7	4.4	0	0	4.3	
	All	2.1	3.7	—	0	—	
	PP	10.4	23.3	0	0	8.3	
	DF	12.9	24.9	0	1.6	15.9	
	LP	14.4	24.1	0	4.2	19.4	
Large	L	17.7	28.4	0	5.9	23.5	
	S-F	23.8	38.6	0	8.6	33.4	
	C-H	29.4	48.8	0	12.5	38.6	
	All	17.4	31.2	—	4.4	—	
	PP	13	25	0	2	14	
	DF	16	26	1	5	20	
	LP	18	25	2	8	24	
Total woody material	L	21	29	2	10	29	
	S-F	27	39	2	12	37	
	C-H	33	50	4	17	43	
	All	21	32	—	9	—	
			Inches				
	PP	0.6	1.1	0	0.2	0.8	
	DF	.9	1.2	0	.5	1.3	
	LP	1.1	1.3	.2	.7	1.5	
Duff depth	L	1.2	1.4	.2	.8	1.6	
	S-F	1.4	1.7	.1	.8	2.0	
	C-H	1.4	1.9	.1	.8	2.0	
	All	1.1	1.5	—	.7	—	

Table 10.—Loadings of downed woody material and depths of forest floor duff by National Forests and habitat type groups from Forest Survey data

Fuel category	Habitat type group	Mean	Standard deviation	First quartile	Median	Third quartile	Number points
		Tons/acre					
		Bitterroot National Forest					
¼ to 1 inch	2	0.5	0.8	0	0	0.8	226
	3	.5	.8	0	0	.8	504
	4	.5	.9	0	0	.5	691
	5	.4	.6	0	0	.5	210
1 to 3 inch	2	1.2	2.7	0	0	2.1	
	3	1.1	2.7	0	0	0	
	4	1.2	2.8	0	0	0	
	5	1.1	2.2	0	0	2.1	
Large	2	9.5	16.3	0	.6	14.9	
	3	7.2	16.5	0	0	7.1	
	4	10.7	21.1	0	0	12.5	
	5	12.7	20.3	0	0	17.6	
Total woody material	2	11	18	0	2	16	
	3	9	18	0	0	11	
	4	12	22	0	1	16	
	5	14	22	0	2	20	
		Inches					
Duff depth	2	0.6	0.9	0	0.1	1.0	
	3	.5	.9	0	0	.6	
	4	.5	1.1	0	0	.5	
	5	.5	.9	0	0	.6	
		Tons/acre					
		Clearwater National Forest					
¼ to 1 inch	3	2.0	1.4	0.9	1.6	2.6	30
	4	.9	1.1	0	.6	1.3	515
	5	1.2	1.2	.3	.9	1.7	821
	7	1.4	1.3	.5	1.1	2.1	1,086
1 to 3 inch	3	1.6	3.4	0	0	2.4	
	4	1.6	3.4	0	0	2.2	
	5	2.0	3.9	0	0	2.4	
	7	3.6	5.7	0	2.2	5.0	
Large	3	4.3	10.0	0	0	3.3	
	4	10.2	23.8	0	0	11.8	
	5	17.4	31.9	0	2.1	22.4	
	7	19.1	32.3	0	2.8	26.2	
Total woody material	3	8	11	2	4	11	
	4	13	25	0	3	15	
	5	21	33	1	7	27	
	7	24	34	2	11	32	
		Inches					
Duff depth	3	0.2	0.3	0	0.1	0.3	
	4	.5	1.1	0	.1	.5	
	5	1.1	1.4	.1	.5	1.5	
	7	1.0	1.5	.1	.5	1.5	

(Con.)

Table 10.—(Con.)

Fuel category	Habitat type group	Mean	Standard deviation	First quartile	Median	Third quartile	Number points
		Tons/acre					
		Colville National Forest					
¼ to 1 inch	2	1.3	1.3	0.3	1.0	2.0	1,703
	3	1.5	1.2	.6	1.3	2.2	249
	4	1.3	1.2	.3	1.1	2.0	741
	5	1.6	1.3	.5	1.3	2.4	643
1 to 3 inch	2	3.0	4.9	0	2.1	4.4	
	3	2.2	3.4	0	0	2.3	
	4	2.5	3.9	0	2.1	4.3	
	5	2.9	4.2	0	2.1	4.5	
Large	2	20.0	32.4	0	6.6	26.9	
	3	16.4	24.4	0	5.5	21.4	
	4	26.1	37.8	0	11.2	36.4	
	5	17.5	24.4	0	8.3	26.4	
Total woody material	2	24	34	3	12	33	
	3	20	25	2	11	27	
	4	30	39	4	16	42	
	5	22	26	4	14	32	
		Inches					
Duff depth	2	0.8	1.1	0.1	0.5	1.2	
	3	1.0	1.2	.3	.8	1.4	
	4	1.5	1.5	.3	1.0	2.2	
	5	1.2	1.3	.3	.9	1.6	
		Tons/acre					
		Deerlodge National Forest					
¼ to 1 inch	1	0.8	0.9	0	0.5	1.1	186
	2	.8	.9	0	.5	1.1	757
	3	.7	.9	0	.3	.9	254
	4	.7	.9	0	.5	1.1	766
	5	.6	.7	0	.3	.8	458
	6	.7	.9	0	.5	.8	181
1 to 3 inch	1	1.8	3.3	0	0	2.2	
	2	1.7	3.0	0	0	2.2	
	3	1.3	2.8	0	0	2.1	
	4	1.7	2.8	0	0	2.2	
	5	1.7	2.8	0	0	2.2	
	6	1.5	2.3	0	0	2.2	
Large	1	14.6	22.0	0	5.9	20.2	
	2	9.7	18.3	0	1.5	12.6	
	3	18.7	24.4	0	9.8	26.1	
	4	18.6	25.7	0	10.1	27.1	
	5	14.4	33.6	0	6.3	19.1	
	6	9.2	14.1	0	3.3	12.4	
Total woody material	1	17	23	1	9	21	
	2	12	19	1	5	17	
	3	21	25	2	12	29	
	4	21	26	3	13	30	
	5	17	34	1	9	22	
	6	11	15	1	5	16	
		Inches					
Duff depth	1	1.3	1.0	0.4	1.2	1.8	
	2	1.0	1.1	.2	.8	1.6	
	3	1.5	1.6	.4	1.0	2.2	
	4	1.5	1.4	.4	1.2	2.1	
	5	1.2	1.3	.3	.9	1.8	
	6	.9	1.1	.1	.5	1.5	

(Con.)

Table 10.—(Con.)

Fuel category	Habitat type group	Mean	Standard deviation	First quartile	Median	Third quartile	Number points
		Tons/acre					
		Flathead National Forest					
¼ to 1 inch	2	0.6	0.7	0	0.3	0.9	45
	3	1.0	1.1	.3	.6	1.4	251
	4	1.0	1.1	.3	.6	1.4	436
	5	1.0	1.0	.3	.7	1.4	1,188
	6	1.0	1.1	0	.8	1.4	123
	7	1.2	1.1	.3	.9	1.6	406
1 to 3 inch	2	1.6	2.5	0	0	2.3	
	3	2.0	3.0	0	0	2.4	
	4	2.2	4.1	0	0	2.3	
	5	1.9	3.1	0	0	2.3	
	6	1.7	3.5	0	0	2.2	
	7	2.1	4.0	0	0	2.3	
Large	2	20.0	28.6	0	8.3	23.9	
	3	13.2	22.0	0	4.9	16.3	
	4	17.4	23.7	0	8.0	26.8	
	5	23.0	31.9	0	11.3	32.8	
	6	27.3	52.2	1.2	14.6	33.8	
	7	21.5	29.2	1.3	11.3	29.7	
Total woody material	2	22	29	2	11	28	
	3	16	23	2	8	20	
	4	21	25	2	11	32	
	5	26	33	3	14	38	
	6	30	52	4	18	36	
	7	25	30	5	15	34	
		Inches					
Duff depth	2	0.9	0.8	0.2	0.9	1.2	
	3	.9	1.0	.3	.8	1.3	
	4	1.3	1.5	.3	.8	1.7	
	5	1.7	1.7	.5	1.3	2.3	
	6	2.0	1.5	.9	1.6	2.9	
	7	1.6	1.7	.5	1.3	2.2	
		Tons/acre					
		Gallatin National Forest					
¼ to 1 inch	1	0.5	0.8	0	0.3	0.7	39
	2	.7	.8	0	.5	.8	54
	3	1.0	1.1	.3	.7	1.3	274
	4	.9	.9	.3	.6	1.2	847
	5	1.1	1.1	.3	.9	1.6	128
	6	.8	.8	.3	.8	1.1	112
1 to 3 inch	1	.7	1.4	0	0	0	
	2	.9	1.5	0	0	2.2	
	3	1.7	3.6	0	0	2.2	
	4	2.0	4.0	0	0	2.2	
	5	1.9	2.8	0	0	2.4	
	6	1.2	2.4	0	0	2.1	
Large	1	6.2	16.6	0	0	3.7	
	2	5.7	12.4	0	0	4.4	
	3	6.9	13.1	0	0	8.5	
	4	17.9	29.2	0	6.4	24.6	
	5	24.2	50.0	1.4	13.9	25.1	
	6	17.8	45.3	0	4.9	17.1	
Total woody material	1	7	17	0	1	5	
	2	7	13	1	3	7	
	3	10	14	1	4	13	
	4	21	31	2	10	29	
	5	27	52	4	16	30	
	6	20	46	1	6	22	
		Inches					
Duff depth	1	0.6	0.9	0	0.1	0.9	
	2	.8	.7	.1	.5	1.2	
	3	1.1	1.4	.2	.7	1.5	
	4	1.1	1.3	.2	.8	1.6	
	5	1.5	1.4	.5	1.2	2.1	
	6	1.0	1.4	.2	.5	1.3	

(Con.)

Table 10.—(Con.)

Fuel category	Habitat type group	Mean	Standard deviation	First quartile	Median	Third quartile	Number points
		Tons acre					
		Helena National Forest					
¼ to 1 inch	1	0.4	0.7	0	0	0.6	352
	2	.8	.9	0	5	1.1	423
	3	.7	.9	0	5	1.1	623
	4	.6	.8	0	5	.9	786
	5	.8	.9	3	5	1.1	284
	6	.6	.7	0	3	8	229
1 to 3 inch	1	.7	2.1	0	0	0	
	2	1.2	2.4	0	0	2.1	
	3	1.3	2.5	0	0	2.1	
	4	1.5	2.9	0	0	2.2	
	5	1.7	2.7	0	0	2.2	
	6	.8	1.6	0	0	2.1	
Large	1	2.9	8.4	0	0	1.2	
	2	11.9	23.1	0	1 4	14.3	
	3	7.4	17.5	0	0	8.3	
	4	11.2	18.8	0	2.9	15.9	
	5	15.5	20.6	1.2	8.1	21.2	
	6	9.9	21.4	0	0	11.2	
Total woody material	1	4	9	0	0	4	
	2	14	24	1	4	16	
	3	10	18	1	3	11	
	4	13	19	1	6	19	
	5	18	21	3	11	26	
	6	11	22	0	3	14	
		Inches					
Duff depth	1	0.4	0.8	0	0	0.5	
	2	.7	.8	0	4	1.0	
	3	1.1	1.1	.2	8	1.6	
	4	.9	1.2	1	6	1.3	
	5	1.3	1.3	.3	1 1	2.0	
	6	.8	1.0	0	3	1.1	
		Tons acre					
		Kaniksu National Forest					
¼ to 1 inch	2	1.0	1.3	0	0.2	1.8	10
	3	.8	1.0	0	.5	1.2	242
	4	1.1	1.0	.4	.9	1.6	72
	5	.9	.9	.3	.8	1.4	256
	7	1.1	1.1	3	.8	1.7	1,315
1 to 3 inch	2	1.8	2.6	0	0	4.3	
	3	1.2	2.5	0	0	2.1	
	4	2.6	3.8	0	0	3.3	
	5	1.9	3.3	0	0	2.2	
	7	2.1	3.5	0	0	2.3	
Large	2	4.2	13.3	0	0	0	
	3	6.8	15.2	0	0	6.3	
	4	19.2	31.2	0	4.3	28.2	
	5	23.1	27.1	1.6	13.3	34.2	
	7	23.5	40.9	0	7.5	30.5	
Total woody material	2	7	15	0	0	8	
	3	9	16	0	2	10	
	4	23	31	3	9	30	
	5	26	28	5	17	37	
	7	26	42	3	11	35	
		Inches					
Duff depth	2	0.8	0.9	0	0.8	1.7	
	3	.9	1.1	0	.5	1.3	
	4	1.1	1.6	3	.7	1.4	
	5	1.3	1.8	2	.7	1.7	
	7	1.5	1.8	.2	.9	2.0	

(Con.)

Table 10.—(Con.)

Fuel category	Habitat type group	Mean	Standard deviation	First quartile	Median	Third quartile	Number points
				Tons acre			
				Kootenai National Forest			
	2	1.0	1.0	0	0.3	0.9	340
	3	.9	1.1	0	.5	1.3	803
¼ to 1 inch	4	1.0	1.0	.3	.6	1.4	516
	5	.9	1.0	0	.5	1.4	617
	6	.3	.6	0	0	.3	21
	7	1.3	1.2	.3	.9	1.8	1,302
	2	1.9	3.2	0	0	2.2	
	3	1.7	3.3	0	0	2.3	
1 to 3 inch	4	2.2	3.5	0	0	2.5	
	5	2.0	3.7	0	0	2.2	
	6	.7	1.3	0	0	0	
	7	2.2	3.3	0	0	4.3	
	2	13.6	18.4	0	0	7.5	
	3	9.1	17.1	0	1.2	10.8	
	4	19.1	30.4	0	6.2	25.2	
Large	5	20.2	34.3	0	6.3	24.8	
	6	5.9	13.5	0	0	6.9	
	7	23.0	43 7	0	8.6	27.6	
	2	17	19	0	3	11	
Total	3	12	19	1	4	16	
woody	4	22	31	3	11	29	
material	5	23	35	2	10	30	
	6	7	13	0	2	9	
	7	27	44	4	12	32	
				Inches			
	2	1.2	1.0	0	0.5	1.3	
	3	1.3	1.3	.2	1.0	1.8	
Duff	4	1.6	1.7	.4	1.1	2.2	
depth	5	1.6	1.8	.1	1.1	2.3	
	6	.6	1.2	0	0	5	
	7	1.9	1.9	.6	1.4	2.5	
				Tons acre			
				Lolo National Forest			
	2	0.9	1.2	0	0.6	1.3	275
	3	1 0	1.1	.3	.6	1.5	780
¼ to 1 inch	4	1.2	1.2	.3	.9	1.8	842
	5	1.1	1.1	.3	.8	1.5	609
	6	.8	.9	0	.6	1.1	183
	7	1.5	1.9	.5	1.1	2.0	261
	2	1.2	2.8	0	0	2.2	
	3	1.4	2.8	0	0	2.3	
1 to 3 inch	4	2.2	3.4	0	0	2.5	
	5	1.7	2.9	0	0	2.3	
	6	1.3	2.5	0	0	2.2	
	7	2.2	3.9	0	0	2.5	
	2	7.3	19.6	0	0	4.3	
	3	9.0	17.5	0	1.2	9.8	
Large	4	16.6	29.5	0	3.8	20.2	
	5	25.3	43.2	0	10.8	33.1	
	6	8 8	13.7	0	1.7	11.8	
	7	14.3	20.5	0	5.6	20.0	
	2	9	21	0	2	9	
Total	3	11	18	1	4	15	
woody	4	20	30	2	9	25	
material	5	28	44	3	14	36	
	6	11	14	1	5	15	
	7	18	21	4	9	26	
				Inches			
	2	0.7	1.1	0	0.4	1.1	
	3	1.1	1.2	.3	.8	1.4	
Duff	4	1.3	1.3	.3	.9	1.8	
depth	5	1.4	1.5	.3	.10	1.8	
	6	.9	.9	.2	.6	1.4	
	7	1.6	1.8	.5	1.1	2.0	

(Con.)

Table 10.—(Con.)

Fuel category	Habitat type group	Mean	Standard deviation	First quartile	Median	Third quartile	Number points
		Tons acre					
		Nezperce National Forest					
	2	0.4	.07	0	0	0.7	20
	3	1.1	1.2	.3	.7	1.4	380
¼ to 1 inch	4	1.0	1.1	3	.7	1.4	891
	5	1.0	1.1	0	.8	1.5	178
	6	.6	.8	0	.3	.9	145
	7	1.3	1.1	.5	1.0	1.8	656
	2	.1	.6	0	0	0	
	3	1.4	2.8	0	0	2.5	
1 to 3 inch	4	1.8	3.3	0	0	2.3	
	5	1.5	2.8	0	0	2.2	
	6	1.2	2.1	0	0	2.2	
	7	2.3	3.5	0	0	2.7	
	2	5.2	22.7	0	0	0	
	3	13.8	30.0	0	0	14.9	
Large	4	17.7	27.8	0	5.6	25.9	
	5	19.1	34.8	0	2.1	23.5	
	6	11.3	18.6	0	0	17.8	
	7	8.4	32.0	0	3.5	24.7	
	2	6	23	0	0	1	
	3	16	31	1	3	20	
Total	4	21	29	1	9	29	
woody	5	22	36	1	5	26	
material	6	13	20	0	3	18	
	7	22	33	2	8	29	
		Inches					
	2	0.3	0.7	0	0	0.4	
	3	.5	1.0	0	.2	.5	
Duff	4	.8	1.1	.1	.5	1.1	
depth	5	.7	1.1	0	.2	.9	
	6	.3	.7	0	0	.4	
	7	.9	1.2	.1	.5	1.3	
		Tons acre					
		St. Joe National Forest					
	3	1.0	1.0	0.3	0.8	1.3	52
¼ to 1 inch	5	1.0	1.2	0	.5	1.6	191
	7	1.0	1.1	0	.8	1.6	720
	3	1.3	1.9	0	0	2.1	
1 to 3 inch	5	.8	2.9	0	0	2.1	
	7	2.2	3.3	0	0	4.3	
	3	9.3	33.4	0	0	1.5	
Large	5	22.2	34.6	0	7.6	30.8	
	7	14.2	28.3	0	2.1	18.8	
Total	3	12	34	1	2	6	
woody	5	25	35	2	11	36	
material	7	17	29	0	7	23	
		Inches					
Duff	3	0.4	0.6	0	0.2	0.6	
depth	5	.6	1.1	0	.3	.9	
	7	.8	1.1	0	.4	1.0	

(Con.)

Table 10.—(Con.)

Fuel category	Habitat type group	Mean	Standard deviation	First quartile	Median	Third quartile	Number points
		Tons/acre					
		Eastside Forests					
¼ to 1 inch	1	0.7	0.8	0	0.5	1.1	577
	2	.9	1.0	0	.6	1.2	1,234
	3	.7	1.0	0	.3	1.1	1,151
	4	.7	.9	0	.5	1.1	2,320
	5	.6	.8	0	.3	.9	870
	6	.6	.7	0	.5	.8	123
1 to 3 inch	1	1.6	2.9	0	0	2.2	
	2	1.6	3.6	0	0	2.2	
	3	1.4	2.7	0	0	2.1	
	4	1.7	3.0	0	0	2.2	
	5	1.3	2.5	0	0	2.2	
	6	1.5	2.4	0	0	2.2	
Large	1	8.5	16.8	0	1.2	10.8	
	2	10.5	21.4	0	1.6	12.5	
	3	11.3	20.6	0	1.3	14.5	
	4	17.0	30.2	0	7.3	23.2	
	5	16.9	17.2	0	2.1	10.6	
	6	9.4	14.9	0	1.6	12.6	
Total woody material	1	11	18	0	4	14	
	2	13	23	1	5	16	
	3	13	22	0	4	18	
	4	19	31	2	10	27	
	5	19	18	1	5	13	
	6	12	15	1	6	15	
		Inches					
Duff depth	1	1.1	1.1	0.2	0.8	1.6	
	2	1.0	1.1	.2	.7	1.5	
	3	.9	1.2	.1	.6	1.4	
	4	1.2	1.3	.3	.9	1.8	
	5	1.0	1.2	.1	.6	1.4	
	6	.7	.9	.1	.3	1.0	
		Tons/acre					
		Westside Forests					
¼ to 1 inch	2	1.1	1.2	0	0.8	1.7	2,569
	3	.9	1.1	0	.6	1.4	3,287
	4	1.1	1.2	.3	.8	1.6	5,348
	5	1.0	1.1	.3	.7	1.4	3,937
	6	.8	1.0	0	.5	1.1	474
	7	1.2	1.2	.3	.9	1.9	5,460
1 to 3 inch	2	2.5	4.4	0	0	4.3	
	3	1.5	2.9	0	0	2.2	
	4	2.1	3.6	0	0	2.4	
	5	1.8	3.3	0	0	2.3	
	6	1.3	2.6	0	0	2.2	
	7	2.4	4.1	0	0	4.3	
Large	2	15.9	29.2	0	3.0	19.1	
	3	10.0	20.4	0	0	11.0	
	4	17.3	28.4	0	4.8	23.7	
	5	21.0	33.8	0	7.8	29.4	
	6	14.3	30.8	0	3.4	19.7	
	7	20.3	36.9	0	5.9	26.0	
Total woody material	2	19	31	1	8	24	
	3	12	21	0	4	16	
	4	21	29	1	9	28	
	5	24	35	2	11	33	
	6	16	31	1	6	22	
	7	24	38	3	11	30	
		Inches					
Duff depth	2	0.8	1.0	0	0.4	1.1	
	3	.9	1.1	0	.5	1.3	
	4	1.1	1.4	.1	.6	1.5	
	5	1.4	1.6	.2	.9	1.9	
	6	1.0	1.2	0	.5	1.5	
	7	1.3	1.7	.2	.9	1.8	

APPENDIX II

Variation in Data and Correlation Between Fuel Variables

Variation in the Data

Distribution of one-fourth to 1-inch (0.25 to 2.5-cm), 1- to 3-inch (2.6- to 7.5-cm), and over 3-inch (7.6-cm) diameter downed woody loadings were examined for many subsets of the data. In all cases, a high degree of variation was found. The distributions were highly skewed, all having long right-handed tails and many zero observations as is illustrated in figure 13. The high degree of variation is partly due to sampling with short transects as the basis for observation. Essentially, sampling was done with very small plots. Additionally, downed woody material is unevenly distributed over the forest floor; a sample transect may have occurrences of no fuel or of jackpots of material. The jackpots cause very high loadings on some points, thus, creating the long-tailed distributions. These high loadings inordinately affect means, which overestimate the center of loading distributions. The mean and standard deviation present a distributional picture that can be misleading.

For these reasons, tables 9 and 10 include the quartiles (Q1, 25th percentile; Q2, 50th percentile or median; and Q3, 75th percentile) as statistics that might reflect fuel loadings in a more realistic manner for evaluation of fire behavior potential. The second quartile, or median, is the halfway point of the ranked data. About 50 percent of the area has loadings less than this figure, while about 50 percent has greater loadings. In all data sets that we analyzed, medians were less than arithmetic means, again pointing out the positive skewness of the distributions. Total loadings ratios of medians to means calculated for combinations of cover types and National Forests averaged 0.43 and ranged from 0.11 to 0.80. The interquartile range, Q3 to Q1 (tables 9 and 10), is a measure of the variability of the ranked data. It shows the spread of the middle 50 percent of the data. For the fuel distributions, it is a more meaningful expression of variation than the standard deviation.

Correlations Among Fuel Variables

Relationships between fuel variables were examined using Kendall's and Spearman's nonparametric correlation analysis (Conover 1971). Practically all correlation coefficients were statistically significant due to large amounts of data. Spearman's correlation coefficients were 0.05 to 0.10 greater than those for Kendall. However, correlations were very low indicating little dependence among fuel variables (fig. 14). The practical implication is that quantities of one fuel class such as 1- to 3-inch (2.6- to 7.5-cm) downed woody material cannot be predicted satisfactorily from another fuel class.

The one-fourth to 1-inch (0.25- to 2.5-cm) and 1- to 3-inch (2.6- to 7.5-cm) variables had the highest correlation; nonetheless, the variables were only weakly related. This suggests that such factors as wind and snow breakage may influence downfall of twigs and small branches differently than large branches. Perhaps the rate that limbwood is incorporated into the forest floor duff differs by size of material. The ratio of one-fourth to 1-inch to 1- to 3-inch material averaged about 0.5 for all cover types. The ratio was 0.56 for ponderosa pine, 0.49 for Douglas-fir and spruce-fir, and 0.44 for cedar-hemlock, larch, and lodgepole pine.

Since 0- to one-fourth inch (0- to 0.25-cm) material was omitted from the Northern Region inventories, it could not be correlated with other variables. Extensive fuel loading data from a study in the Selway-Bitterroot Wilderness Area, however, indicated that the 0- to one-fourth inch (0- to 0.25-cm) material was poorly correlated with the one-fourth to 1-inch (0.25- to 2.5-cm) material. For these variables, Spearman's correlation coefficients ranged from 0.23 to 0.47 across six cover types.

Loading of small fuel was poorly correlated with either sound or rotten large fuel. Although not shown in figure 14, correlations between the sum of sound and rotten material and other fuel variables were equally as poor as those for sound and rotten categories alone.

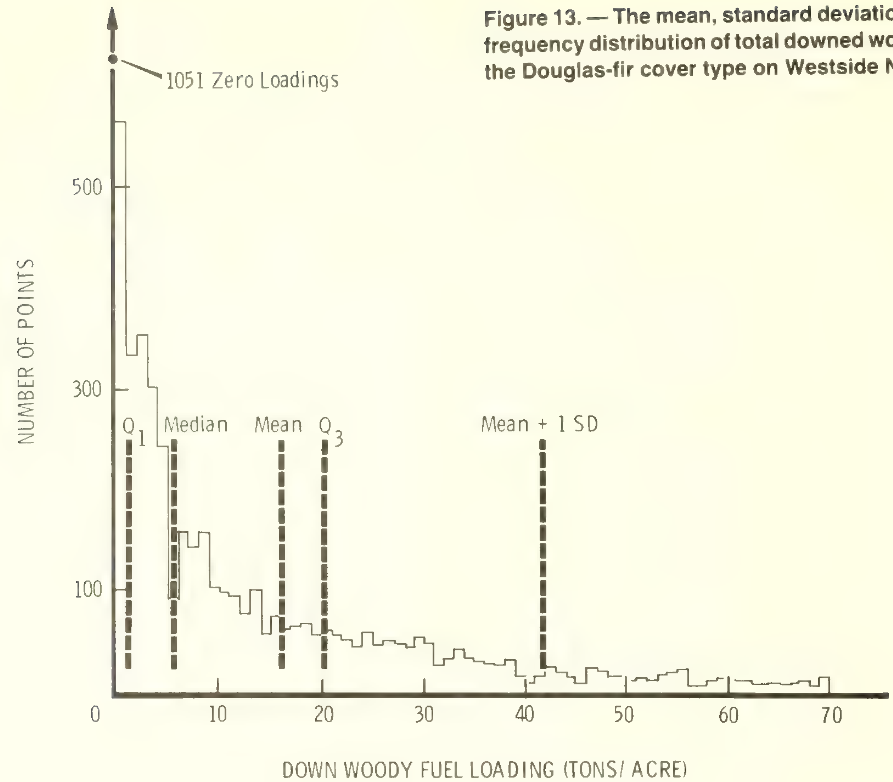

Figure 13. — The mean, standard deviation, quartiles, and frequency distribution of total downed woody loadings for the Douglas-fir cover type on Westside National Forests.

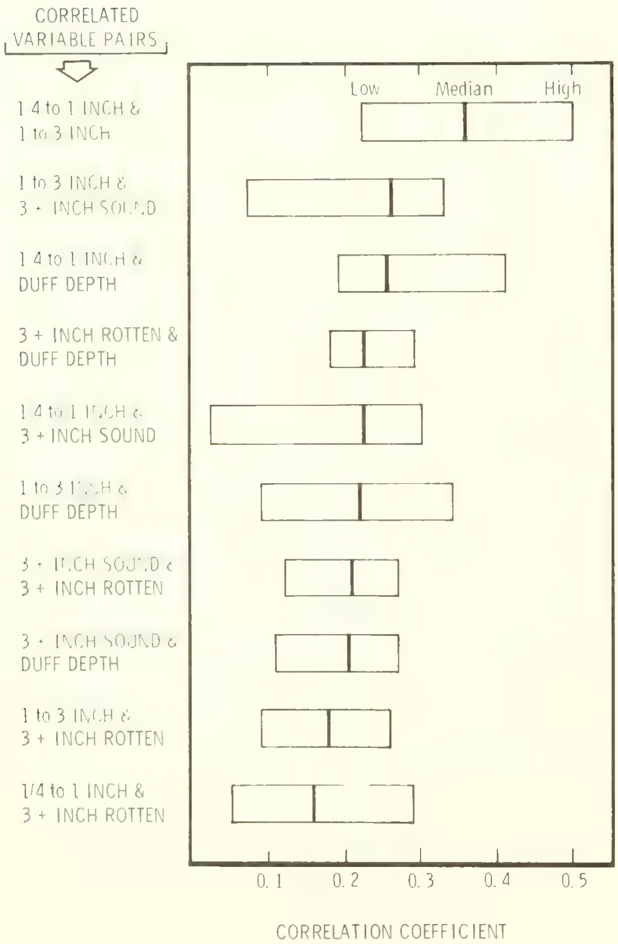

Figure 14. — Kendall's nonparametric correlation coefficients between pairs of fuel variables. The range and median of correlation coefficients from combinations of cover types and National Forests in the Northern Region are shown.

APPENDIX III

Formation of Habitat Type Groups

Habitat types were placed into groups (table 11) based on similarity of loading and correspondence to the habitat type fire groups developed by Davis and others (1980). (See appendix VIII for abbreviations of habitat types shown in table 11.) In the grouping by Davis and others, some habitat type phases were placed into different groups. We chose to place all phases of a habitat type into one group. Placement of habitat types into groups was based on the most commonly occurring phases. A few habitat types from the fire groups (Davis and others 1980) were placed in slightly different loading groups. For example, *Abies grandis/Xerophyllum tenax* from a warm moist fire group was placed in the dry lower subalpine fir loading group because fuel loading, productivity, and associated species were more like the latter group. For the Westside Forests, all dry-site ponderosa pine and Douglas-fir habitat types were placed in Group Two. However, for the Eastside Forests, ponderosa pine and Douglas-fir bunch grass habitat types were placed in Group One, while dry-site Douglas-fir habitat types were placed in Group Two. The ordination in figure 11 showed distinctly different loadings and productivities for the bunch grass types, thus a separate group seemed desirable. Apparently, limited stocking in the bunch grass types (Pfister and others 1977) resulted in lower productivities and loadings than other types on the Eastside. On the Westside, loadings and productivities of all dry-site habitat types seemed enough alike to justify one group (fig. 10).

The number of sample stands in table 11 indicates the relative occurrence of habitat types over the inventoried forest lands. On the Westside, the five most commonly occurring habitat types, *Abies lasiocarpa/Clintonia, Thuja/Clintonia, Pseudotsuga/Physocarpus, Tsuga heterophylla/Clintonia,* and *Abies lasiocarpa/Xerophyllum,* accounted for 53 percent of the sampled stands. On the Eastside, *Pseudotsuga/Calamagrostis rubescens, Abies lasiocarpa/Xerophyllum, Abies lasiocarpa/Pinus albicaulis - Vaccinium scoparium, Abies lasiocarpa/Vaccinium scoparium,* and *Pseudotsuga/Symphoricarpos albus* accounted for 40 percent of the stands. Most of the *Abies lasiocarpa/Xerophyllum* for the Eastside was from west of the Continental Divide.

Some habitat types fail to appear in table 11 because they were not sampled. To apply results of this paper to unmentioned habitat types, select the group that appears most similar ecologically. The fire groups by Davis and others (1980) will be helpful for this. Equivalence between the fire and loading habitat type groups is as follows:

Loading Groups	**Fire Groups** (Davis and others 1980)
1	1,2
2 Eastside	3,4,5
2 Westside	2,3,4,5
3	6
4	7,8
5	9
6	10
7	11

Table 11.—Groups of habitat types for relating to loading. Number of stands sampled is shown beside each habitat type (see appendix VIII for abbreviations of habitat types)

Groups[1]						
1 PIFL: PIPO and PSME bunch grass types	2 Dry-site PSME moist-site PIPO	3 Moist site PSME	4 Cool-site, PICO-dominated and dry, lower ABLA	5 Moist-site lower ABLA	6 Cold, moist-site upper ABLA	7 Warm, moist-sites
			WESTSIDE			
	PSME/CARU 118	PSME/PHMA 315	ABLA/XETE 264	ABLA/CLUN 337	ABLA/LUHI 73	THPL/CLUN 337
	PSME/FEID 29	PSME/VAGL 112	ABGR/XETE 122	ABLA/MEFE 182	PIAL/ABLA 9	TSHE/CLUN 276
	PSME/AGSP 26	PSME/SYAL 63	ABLA/VASC 61	TSME/MEFE 60	ABLA/RIMO 1	ABGR/CLUN 176
	PSME/FESC 11	PSME/LIBO 38	TSME/XETE 57	ABLA/LIBO 42	ABLA/PIAL 1	THPL/OPHO 8
	PSME/CAGE 7	PSME/VACA 34	ABLA/VACA 21	ABLA/ALSI 11		
	PSME/ARUV 3		PICEA/LIBO 20	PICEA/CLUN 8		
	PSME/SPBE 1		ABLA/VAGL 5	ABLA/OPHO 5		
	PIPO/AGSP 1		PICEA/VACA 2	ABLA/GATR 2		
	PIPO/SYAL 1		ABLA/CARU 1	ABLA/CACA 2		
			ABLA/CLPS 1			
			EASTSIDE			
PSME/FEID 47	PSME/CARU 136	PSME/SYAL 79	ABLA/XETE 117	ABLA/LIBO 54	ABLA-PIAL/VASC 113	
PIPO/FEID 36	PSME/JUCO 42	PSME/PHMA 67	ABLA/VASC 82	ABLA/MEFE 36	ABLA/LUHI 16	
PIPO/AGSP 27	PIPO/SYAL 35	PSME/LIBO 26	ABLA/VAGL 55	ABLA/CACA 25	PIAL/ABLA 15	
PIPO/AND 15	PSME/CAGE 19	PSME/VAGL 24	ABLA/CARU 23	ABLA/ALSI 19	PICEA/SEST 3	
PIFL/JUCO 10	PIPO/PRVI 16	PSME/VACA 8	ABLA/ARCO 22	ABLA/GATR 14	PIAL 3	
PSME/FESC 10	PSME/ARUV 13					
PIFL/FEID 8	PSME/ARCO 5		ABLA/CLPS 16	PICEA/GATR 3	LALY/ABLA 1	
PSME/AGSP 8	PSME/SPBE 4		PICEA/LIBO 15	ABLA/CLUN 1		
PIPO/PUTR 3			PICO SERIES 15			
PIFL/AGSP 1			ABLA/VACA 10			
			PICEA/SMST 8			
			PICEA/PHMA 7			
			ABLA/CAGE 4			

[1]1 — Limber pine (*Pinus flexilis*); ponderosa pine, and Douglas-fir/bunch grass types.
2 — Dry site Douglas-fir and moist site ponderosa pine
3 — Moist site Douglas-fir
4 — Cool sites dominated by lodgepole pine; dry, lower elevation subalpine fir.
5 — Moist site, lower elevation subalpine fir
6 — Cold, moist site upper elevation subalpine fir.
7 — Warm, moist sites; mostly cedar-hemlock.

APPENDIX IV

Diameters of Large Downed Woody Material

The loadings of large material by diameter class were determined for five groups of habitat types selected from Forest Survey data to represent widely occurring cover types. Percentages of large material by diameter class are shown in table 12 for sound material and in table 13 for rotten material.

Table 12.—Percentages of sound downed woody material loadings by diameter class and habitat type within National Forests. Number of sample points are in parentheses

Habitat type[1]	Cover type[2]	Diameter	National Forest											
			Custer	Gallatin	Deerlodge	Helena	Beaverhead	Lolo	Bitterroot	Flathead	Kootenai	Nezperce	Clearwater	Kaniksu
		Inches	*Percent*											
ABLA VASC	LP	3-6	65	14	19	29	23	20	13	24	14	15	14	13
ABLA XETE		6-10	35	32	41	43	47	39	28	36	31	43	29	17
		10-20	0	54	30	28	29	31	17	36	50	36	47	70
		20 +	0	0	10	0	1	10	42	4	5	6	10	0
			(33)	(285)	(607)	(615)	(1,001)	(444)	(159)	(422)	(311)	(397)	(349)	(121)
PSME PHMA	DF	3-6	64	19	22	32	—	27	13	—	33	17	7	24
PSME VAGL		6-10	22	26	64	32	—	39	22	—	28	23	50	25
		10-20	14	42	14	36	—	34	40	—	35	29	43	35
		20 +	0	13	0	0	—	0	25	—	4	31	0	16
			(93)	(301)	(127)	(149)		(358)	(143)		(448)	(394)	(31)	(235)
THPL CLUN	C-H	3-6	—	8	—	—	—	19	—	19	16	9	9	13
TSHE/CLUN		6-10	—	33	—	—	—	37	—	26	27	19	31	17
		10-20	—	59	—	—	—	44	—	48	36	51	46	43
		20 +	—	0	—	—	—	0	—	7	21	21	14	27
				(47)				(122)		(119)	(1,203)	(228)	(910)	(1,473)
ABLA/CLUN	S-F	3-6	—	—	25	32	—	13	24	14	10	9	9	9
ABLA/MEFE		6-10	—	—	39	46	—	35	68	29	22	23	18	21
TSHE/MEFE		10-20	—	—	36	22	—	48	8	41	42	49	40	52
		20 +	—	—	0	0	—	4	0	16	26	19	33	18
					(152)	(107)		(571)	(168)	(1,066)	(583)	(152)	(824)	(332)
ABGR/CLUN	L	3-6	—	27	—	—	—	15	—	13	25	13	15	—
		6-10	—	54	—	—	—	37	—	25	23	22	8	—
		10-20	—	19	—	—	—	48	—	52	14	35	35	—
		20 +	—	0	—	—	—	0	—	10	38	30	42	—
				(82)				(139)		(321)	(136)	(395)	(212)	

[1]See appendix VIII for abbreviations for habitat types.

[2]1 = Limber pine q(*Pinus flexilis*); ponderosa pine, and Douglas-fir/bunch grass types
2 = Dry site Douglas-fir and moist site ponderosa pine.
3 = Moist site Douglas-fir
4 = Cool sites dominated by lodgepine; dry, lower elevation subalpine fir.
5 = Moist site, lower elevation subalpine fir.
6 = Cold, moist site upper elevation subalpine fir.
7 = Warm, moist sites; mostly cedar-hemlock.

Table 13.—Percentages of rotten downed woody material loadings by diameter class and habitat type within National Forests. Number of sample points are in parentheses.

Habitat type[1]	Cover type[2]	Diameter	National Forest											
			Custer	Gallatin	Deerlodge	Helena	Beaverhead	Lolo	Bitterroot	Flathead	Kootenai	Nezperce	Clearwater	Kaniksu
		Inches	*Percent*											
ABLA/VASC	LP	3-6	31	10	17	15	17	14	10	10	8	13	4	8
ABLA/XETE		6-10	58	34	39	34	45	38	37	34	36	31	13	16
		10-20	11	53	37	49	36	46	43	44	56	49	47	69
		20 +	0	3	7	2	2	2	9	11	0	7	36	7
			(33)	(285)	(607)	(615)	(1,001)	(444)	(159)	(422)	(311)	(397)	(349)	(121)
PSME/PHMA	DF	3-6	38	12	25	17	—	11	8	—	10	5	20	10
PSME/VAGL		6-10	29	30	40	36	—	27	18	—	19	11	27	19
		10-20	33	58	27	47	—	49	44	—	46	50	53	71
		20 +	0	0	8	0	—	13	30	—	25	34	0	0
			(93)	(301)	(127)	(149)		(358)	(143)		(448)	(394)	(31)	(235)
THPL/CLUN	C-H	3-6	—	3	—	—	—	5	—	9	9	7	3	5
TSHE/CLUN		6-10	—	15	—	—	—	31	—	42	22	16	18	12
		10-20	—	36	—	—	—	56	—	49	45	46	52	48
		20 +	—	46	—	—	—	8	—	0	24	31	27	35
				(47)				(122)		(119)	(1,203)	(228)	(910)	(1,473)
ABLA/CLUN	S-F	3-6	—	—	25	18	—	10	4	5	8	8	4	7
ABLA/MEFE		6-10	—	—	39	38	—	32	11	22	21	15	16	19
TSHE/MEFE		10-20	—	—	36	29	—	39	4	53	50	47	58	49
		20 +	—	—	0	15	—	19	81	20	21	30	22	25
					(152)	(107)		(571)	(168)	(1,066)	(583)	(152)	(824)	(332)
ABGR/CLUN	L	3-6	—	9	—	—	—	8	—	8	5	4	3	—
		6-10	—	21	—	—	—	27	—	29	7	15	11	—
		10-20	—	22	—	—	—	59	—	63	62	48	43	—
		20 +	—	48	—	—	—	6	—	0	26	33	43	—
				(82)				(139)		(321)	(136)	(395)	(212)	

[1]See appendix VIII for abbreviations for habitat types

[2]1 - Limber pine (*Pinus flexilis* ponderosa pine, and Douglas-fir bunch grass types
2 - Dry site Douglas-fir and moist site ponderosa pine
3 — Moist site Douglas-fir
4 — Cool sites dominated by lodgepine, dry, lower elevation subalpine fir
5 — Moist site, lower elevation subalpine fir
6 - Cold, moist site upper elevation subalpine fir
7 - Warm, moist sites, mostly cedar-hemlock

APPENDIX V

Stand Examination Fuel Summaries by National Forests

Stand examination summaries are biased toward stands designated for management activities. These stands tend to be high risk especially on some National Forests. Loadings of downed woody material and duff depths are summarized in tables 14; and location of samples in table 15.

Table 14.—Means and standard deviations from Stand Examinations by National Forest of downed woody material loadings and duff depths

Cover type	Downed woody material: 0.25 to 1 inch Mean	0.25 to 1 inch S.D.	1 to 3 inches Mean	1 to 3 inches S.D.	Large Mean	Large S.D.	Total Mean	Duff depth Mean	Duff depth S.D.	Number sample points	Rotten
	Tons acre							Inches			Percent
					Beaverhead National Forest						
DF	1.8	2.6	3.7	8.7	10.8	12.2	16	1 2	0.7	275	72
LP	1.5	2.6	3.7	8.0	17.7	21.1	23	1.2	9	1,761	51
S-F	1.7	2.8	3.3	6.1	26 9	25.1	32	2 5	1.7	238	53
					Bitterroot National Forest						
PP	.8	1.0	1.4	1.8	11 3	13.6	14	8	.6	1,685	69
DF	1.6	1.8	2.0	1.8	21.1	19.0	25	1.2	.9	7,158	67
LP	1.0	1.8	1.9	1.6	25.9	21.4	29	1.4	9	1,152	62
S-F	1.7	2.7	2.2	1.8	51.2	21.2	55	2.3	1.4	471	56
					Clearwater National Forest						
PP	1.6	1.4	2.4	1.6	9.7	10.8	14	4	2	317	56
DF	1.5	1.2	2 5	1.8	22.6	19.1	27	1.2	8	6,450	62
LP	1.0	.8	1.8	1.6	19.7	17.7	22	9	.7	1,329	56
L	1.4	.9	2.4	1.9	31.0	25.1	35	1.2	8	9,403	60
S-F	1.3	1.5	2.0	1.8	32.0	21.1	35	1.3	9	6,381	64
C-H	1.5	1.0	2.6	2.3	39.2	27.7	43	1.6	1.0	6,753	57
WP	1.1	.8	2.1	2.1	29.4	22.3	33	1.1	7	588	55
					Custer National Forest						
PP	2.1	1.6	2.3	3.8	6.9	6 6	11	1.0	.5	1,732	35
					Deerlodge National Forest						
DF	1.3	1.4	2.1	2.1	10.0	11.3	13	1.0	6	757	62
LP	.9	.8	2.2	2.2	13.8	19.1	17	1.0	7	2,486	54
S-F	.9	.9	2.6	2.2	24.9	24.0	28	1.5	9	215	62
					Flathead National Forest						
PP	.7	.6	1.1	1.1	9.5	13.1	11	.9	.8	415	55
DF	1.0	.9	2.0	2.1	16.4	18.3	19	1.4	1.1	5,094	57
LP	1.0	.9	2.6	2.6	12.4	13.7	16	1.3	1.1	3,884	46
L	1.1	1.1	2.0	2.3	19.3	20.1	22	1.7	1.4	4,342	52
S-F	1.4	1.4	2.8	3.1	32.5	27.2	37	2.1	1.5	7,303	52
C-H	1.4	1.3	2.6	2.1	33.2	29.9	37	2.4	1.2	349	63
WP	1.2	.9	2.7	3.1	25.0	27.1	29	2.0	1.4	196	58
					Gallatin National Forest						
DF	2.1	1.9	2.5	2.4	15.2	16.0	20	1.5	.7	459	59
LP	1.2	.7	1.8	2.0	19.9	31.4	23	1 7	9	676	43
S-F	1.5	1.0	2.9	2.1	21.0	13.4	25	2.6	1.2	152	56
					Helena National Forest						
PP	0.9	0.7	1.4	1.6	2.3	2.6	5	0.5	0.4	193	76
DF	1.1	1.1	3.0	2.8	16.0	14.7	20	8	6	2,836	48
LP	.8	.6	2.0	1.6	13.0	10.7	16	1.1	.7	2,104	52
S-F	1.3	.8	3.6	2.3	27.3	16.5	32	1.3	1.1	458	54
					Idaho Panhandle National Forests						
PP	1.1	.9	1.8	1.8	12.3	14.6	15	1.1	7	822	53
DF	1.5	1.3	2.7	2.6	16.0	17.1	20	1.3	8	6,567	53
LP	1.4	1.4	2.6	2.4	14.3	17 7	18	1.3	8	3,317	49
L	1.5	1.2	2.9	2.3	28.2	35.8	33	1.4	9	7,222	62
S-F	1.3	.9	2.6	2.4	29.5	29.6	33	1.6	1 0	5,888	52
C-H	1.4	1.2	2.8	2.4	34.3	27.0	38	1.8	1.1	7,744	55
WP	1.3	1.5	2.2	2.5	20.0	20.3	24	1.4	8	1,226	54
					Kootenai National Forest						
DF	2.3	2.4	2.8	2.2	12.2	9.0	17	1.5	1.1	1,703	—
LP	1.2	.9	2.9	3.1	12.5	9.9	17	2.6	2.0	65	–
L	2.9	2.9	3.9	3.8	24.1	26.0	31	2.2	1.9	472	—
S-F	1.5	1.8	1.9	2.0	27.9	20.3	31	1.8	1 3	582	—
C-H	4.8	3.5	6.8	5.9	33.5	27.8	45	2.0	1.4	224	—
					Lewis and Clark National Forest						
PP	1.0	.4	1.3	.8	5.4	6.3	8	8	.5	151	64
DF	4.5	4.7	5.3	7.4	19.9	18.4	30	1.2	.7	572	53
LP	2.5	1.7	3.7	4.2	17.4	13.4	24	6	.7	1,716	36
S-F	3.5	4.2	2.7	2.4	29.2	9.7	35	1 2	1.0	86	23
					Lolo National Forest						
PP	0.9	0.6	1.1	1.2	10.4	9.3	12	0.6	0.8	665	—
DF	1.3	1.6	1.9	1.9	11.9	10.9	15	1.1	6	4,233	—
LP	1.6	1.3	2.4	1.8	15.8	12.6	20	1.1	7	1,591	—
L	1.8	1.3	2.4	1.7	17.5	17.3	22	1.6	7	848	—
S-F	1.8	1.3	2.7	2.6	36.3	23.4	41	1.4	9	767	—
					Nezperce National Forest						
PP	2.6	3.3	3.1	2.4	20.8	8.7	26	8	.5	140	62
DF	2.0	1.7	3.1	2.9	17.1	19.4	22	1.3	8	875	56
LP	1.1	.7	2.3	1.9	13.2	14.1	17	1.4	6	1,506	45
L	1.9	1.9	2.6	2.6	28 4	54.4	33	1.5	1.0	3,109	33
S-F	1.5	1.9	2.0	2.2	25.3	18.6	29	1.3	9	451	61
C-H	2.1	2.3	4.0	3.1	32.7	27.1	39	1.7	1.2	445	57

Table 15.—Number of stands sampled by Forest and Ranger District (R.D.) using Stand Examinations

Westside Forests

National Forest	Cover type[1] DF	S-F	LP	C-H	L	PP
BITTERROOT:						
Darby R.D.	130	12	16		3	66
Stevensville R.D.	59	8	29		3	25
Sula R.D.	674	43	100			113
West Fork R.D.	77		5			11
CLEARWATER:						
Canyon R.D.	154	26	3	206	349	
Kelly Creek R.D.	54	71	46	103	87	
Lochsa R.D.	61	27		36	85	12
Palouse R.D.	47	4	6	48	100	2
Pierce R.D.	52	20	12	161	154	1
Powell R.D.	194	357	37	79	95	2
FLATHEAD:						
Condon R.D.	116	137	106	25	120	28
Glacier View R.D.	58	302	103	2	82	
Hungry Horse R.D.	25	196	25		65	
Spotted Bear R.D.	88	97	71		38	1
Swan Lake R.D.	509	120	234	24	336	38
Tally Lake R.D.	73	104	110		26	
KOOTENAI:						
Fortine R.D.	119	58	8	3	33	
Troy R.D.	63	12	1	34	30	3
LOLO:						
Missoula R.D.	182	30	48		25	23
Ninemile R.D.	132	16	41	2	35	25
Plains R.D.	18	3	18		6	3
Seeley R.D.	29	14	14		7	1
Superior R.D.	9	1	1		1	2
Thompson Flats R.D.	24	2	110		6	8
NEZPERCE:						
Clearwater R.D.	9	1	3		51	11
Elk City R.D.	48	12	75		118	
Red River R.D.	12	19	80		36	1
Salmon R.D.	9	4	2		8	
Selway R.D.	54	31	1	97	145	
IDAHO PANHANDLE:						
Avery R.D.	8	39	1	37	22	
Fernan R.D.	10		4		15	7
Sandpoint R.D.	120	45	34	72	37	11
St. Maries R.D.	93	81	33	146	267	7

Eastside Forests

National Forest	Cover type[1] DF	S-F	LP	C-H	L	PP
BEAVERHEAD:						
Dillion R.D.	48	43	258			
Wisdon R.D.		13				
Wise River R.D.	4	2	21			
CUSTER:						
Ashland R.D.						50
Districts R.D.						73
Sioux R.D.						36
DEERLODGE:						
Butte R.D.	20	1	44			
Deerlodge R.D.	25	13	70			
Jefferson R.D.		5	49			
Philipsburg R.D.	58	17	151			
GALLATIN:						
Big Timber R.D.	42		3			
Bozeman R.D.	17	9	41			
Gardiner R.D.	15	12	57			
Hebgen Lake R.D.		2	11			
Livingston R.D.	3		1			
HELENA:						
District-3 R.D.	67	11	78			4
Helena R.D.	40	3	1			8
Lincoln R.D.	34	6	40	1		
Townsend R.D.	69	3	75			1
LEWIS & CLARK						
Belt Creek R.D.	6		2			1
Judith R.D.	20	4	118			3
Musselshell R.D.	28		16			11
White Sulphur R.D.	27	3	39			

[1]DF = Douglas-fir
S-F = Engelman spruce-subalpine.
LP = Lodgepole pine.
C-H = Western redcedar-western hemlock.
L = Western larch-grand fir.
PP = Ponderosa pine.

APPENDIX VI

Volumes of Large Downed Woody Material

Table 16, summarizing volumes by cover type, was based on volumes per acre in table 4 and commercial forest acreages (see footnote 1). Volumes for the white pine type were computed using the downed woody volume per acre for cedar-hemlock. Volumes per acre for western Montana were averaged from data on the Bitterroot, Lolo, Flathead, and Kootenai National Forests. For northern Idaho, they were averaged from data on the Kaniksu, St. Joe, Clearwater, and Nezperce National Forests.

Table 16.—Volumes of large downed woody material and area of commercial forest land by cover types occurring in western Montana and northern Idaho

Cover type	Western Montana				Northern Idaho			
	Land		Volume		Land		Volume	
	National Forest	All ownerships	National Forest	All ownerships	National Forest	All ownerships	National Forest	All ownerships
	MM acres		M ft^3		MM acres		M ft^3	
DF	1,872	3,128	2,080	3,470	909	1,950	1,290	2,770
PP	186	1,229	95	627	99	585	101	596
S-F	971	1,090	2,220	2,500	565	712	1,060	1,340
C-H	178	192	557	603	615	1,078	1,210	2,110
L	608	1,160	1,120	1,870	1,269	2,265	2,460	4,400
LP	1,737	2,377	2,470	3,380	621	777	876	1,100
WP	34	51	107	160	123	275	241	540
Total			8,649	12,610			7,238	12,856

APPENDIX VII

Photo Interpretation Classes

Table 17.—Definition of photo interpretation classes used to correlate with loadings. Codes are from the Region 1 Stand Analysis Handbook

Photo interpretation class	Region 1 codes
Stand height greater than 40 feet:	
1. Coarse texture (usually mature or overmature sawtimber) well and medium stocked	11, 12
2. Fine texture (small sawtimber or pole stands), well and medium stocked	14, 15
3. Coarse and fine texture, poorly stocked	13, 16
4. Two-storied stands, both stories well and medium stocked	17, 18
Stand height 40 feet or less:	
5. Coarse and fine texture, well and medium stocked	25, 27, 28
6. Coarse and fine texture, poorly stocked	26, 29
Cutover areas, all stand heights:	
7. Well and medium stocked	19, 21, 23, 31
8. Poorly stocked	20, 22, 24, 32, 33

APPENDIX VIII

Habitat Types

Common Name	Scientific Name	Abbreviation	ADP Code
ponderosa pine/Idaho fescue	*Pinus ponderosa/Festuca idahoensis*	PIPO/FEID	140
ponderosa pine/bluestem	*Pinus ponderosa/Andropogon* spp	PIPO/AND	110
limber pine/common juniper	*Pinus flexilis/Juniperus communis*	PIFI/JUCO	070
limber pine/Idaho fescue	*Pinus flexilis/Festuca idahoensis*	PIFL/FEID	050
ponderosa pine/bitterbrush	*Pinus ponderosa/Purshia tridentata*	PIPO/PUTR	160
limber pine/bluebunch wheatgrass	*Pinus flexilis/Agropyron spicatum*	PIFL/AGSP	040
Douglas-fir/pinegrass	*Pseudotsuga menziesii/Calamagrostis rubescens*	PSME/CARU	320
Douglas-fir/Idaho fescue	*Pseudotsuga menziesii/Festuca idahoensis*	PSME/FEID	220
Douglas-fir/bluebunch wheatgrass	*Pseudotsuga menziesii/Agropyron spicatum*	PSME/AGSP	210
Douglas-fir/rough fescue	*Pseudotsuga menziesii/Festuca scabrella*	PSME/FESC	230
Douglas-fir/elk sedge	*Pseudotsuga menziesii/Carex geyeri*	PSME/CAGE	330
Douglas-fir/kinnikinnick	*Pseudotsuga menziesii/Arctostaphylos uva-ursi*	PSME/ARUV	350
Douglas-fir/white spiraea	*Pseudotsuga menziesii/Spiraea betulifolia*	PSME/SPBE	340
ponderosa pine/bluebunch wheatgrass	*Pinus ponderosa/Agropyron spicatum*	PIPO/AGSP	130
ponderosa pine/snowberry	*Pinus ponderosa/Symphoricarpos albus*	PIPO/SYAL	170
Douglas-fir/common juniper	*Pseudotsuga menziesii/Juniperus communis*	PSME/JUCO	360
ponderosa pine/chokecherry	*Pinus ponderosa/Prunus virginiana*	PIPO/PRVI	180
Douglas-fir/heartleaf arnica	*Pseudotsuga menziesii/Arnica cordifolia*	PSME/ARCO	370
Douglas-fir/ninebark	*Pseudotsuga menziesii/Physocarpus malvaceus*	PSME/PHMA	260
Douglas-fir/blue huckleberry	*Pseudotsuga menziesii/Vaccinium globulare*	PSME/VAGL	280
Douglas-fir/snowberry	*Pseudotsuga menziesii/Symphoricarpos albus*	PSME/SYAL	310
Douglas-fir/twinflower	*Pseudotsuga menziesii/Linnaea borealis*	PSME/LIBO	290
Douglas-fir/dwarf huckleberry	*Pseudotsuga menziesii/Vaccinium caespitosum*	PSME/VACA	250
subalpine fir/beargrass	*Abies lasiocarpa/Xerophyllum tenax*	ALBA/XETE	690
grand fir/beargrass	*Abies grandis/Xerophyllum tenax*	ABGR/XETE	510
subalpine fir/grouse whortleberry	*Abies lasiocarpa/Vaccinium scoparium*	ABLA/VASC	730
nmountain hemlock/beargrass	*Tsuga mertensiana/Xerophyllum tenax*	TSME/XETE	710
subalpine fir/dwarf huckleberry	*Abies lasiocarpa/Vaccinium caespitosum*	ABLA/VACA	640
spruce/twinflower	*Picea/Linnaea borealis*	PICEA/LIBO	470
subalpine fir/blue huckleberry	*Abies lasiocarpa/Viccinium globulare*	ABLA/VAGL	720
spruce/dwarf huckleberry	*Picea/Vaccinium caespitosum*	PICEA/VACA	450
subalpine fir/pinegrass	*Abies lasiocarpa/Calamagrostis rubescens*	ABLA/CARU	750
subalpine fir/virgin's bower	*Abies lasiocarpa/Clematis pseudoalpina*	ABLA/CLPS	770
subalpine fir/heartleaf arnica	*Abies lasiocarpa/Arnica cordifolia*	ABLA/ARCO	780
lodgepole pine series	*Pinus contorta* series	PICO SERIES	910 920 930 940 950
spruce/starry Solomon's seal	*Picea/Smilacina stellata*	PICEA/SMST	480
spruce/ninebark	*Picea/Physocarpus malvaceus*	PICEA/PHMA	430
subalpine fir/elk sedge	*Abies lasiocarpa/Carex geyeri*	ABLA/CAGE	790
subalpine fir/queencup beadlily	*Abies lasiocarpa/Clintonia uniflora*	ABLA/CLUN	620
subalpine fir/menziesia	*Abies lasiocarpa/Menziesia ferruginea*	ABLA/MEFE	670
western hemlock/menziesia	*Tsuga heterophylla/Menziesia ferruginea*	TSME/MEFE	680
subalpine fir/twinflower	*Abies lasiocarpa/Linnaea borealis*	ABLA/LIBO	660
subalpine fir/Sitka alder	*Abies lasiocarpa/Alnus sinuata*	ABLA/ALSI	740
spruce/queencup beadlily	*Picea/Clintonia uniflora*	PICEA/CLUN	420
subalpine fir/sweetscented bedstraw	*Abies lasiocarpa/Galium triflorum*	ABLA/GATR	630
subalpine fir/bluejoint	*Abies lasiocarpa/Calamagrostis canadensis*	ABLA/CACA	650
Picea/sweetscented bedstraw	*Picea/Galium trifolium*	PICEA/GATR	440
subalpine fir/smooth wood-rush	*Abies lasiocarpa/Luzula hitchcockii*	ABLA/LUHI	830
whitebark pine-subalpine fir	*Pinus albicaulis-Abies lasiocarpa*	PIAL/ABLA	850
subalpine fir/mountain gooseberry	*Abies lasiocarpa/Ribes montigenum*	ABLA/RIMO	810
subalpine fir-whitebark pine/ grouse whortleberry	*Abies Lasiocarpa-Pinus albicaulis/ Vaccinium scoparium*	ABLA/PIAL/ VASC	820
whitebark pine-subalpine fir	*Pinus albicaulis-Abies lasiocarpa*	PIAL/ABLA	850
spruce/cleftleaf groundsel	*Picea/Senecio streptanthifolius*	PICEA/SEST	460
whitebark pine	*Pinus albicaulis*	PIAL	870
alpine larch-subalpine fir	*Larix lyallii-Abies lasiocarpa*	LALY/ABLA	860
western redcedar/queencup beadlily	*Thuja plicata/Clintonia uniflora*	THPL/CLUN	530
western hemlock/queencup beadlily	*Tsuga heterophylla/Clintonia uniflora*	TSHE/CLUN	570
grand fir/queencup beadlily	*Abies grandis/Clintonia uiflora*	ABGR/CLUN	520
western redcedar/devil's club	*Thuja plicata/Oplopanax horridum*	THPL/OPHO	550

☆ U.S. GOVERNMENT PRINTING OFFICE: 1981 — 777-028/111 Region No. 8

Brown, James K., and Thomas E. See.
1981. Downed dead woody fuel and biomass in the Northern Rocky Mountains. USDA For. Serv. Gen. Tech. Rep. INT-117 48 p. Intermt. For. and Range Exp. Stn., Ogden, Utah 84401.

Weights and volumes of downed woody material in diameter classes of one-fourth to 1, 1 to 3, and greater than 3 inches and forest floor duff depths were summarized from extensive inventories in northern Idaho and Montana. Biomass loadings are shown by cover types and habitat types within National Forests. Total downed woody biomass ranged from 5 tons per acre in ponderosa pine to 33 tons per acre in cedar-hemlock. Relationships for predicting loading from stand age, slope, aspect, and elevation proved ineffectual. Loadings generally increased with increased productivity, but varied greatly with stand age. Fuels tended to become predictably high in overmature stands but unpredictable in young, immature, and mature stands. Forest fuel succession is discussed in relation to tree mortality, fuel buildup, and depletion.

KEYWORDS: forest fuels, biomass, fuel accumulation, forest utilization, forest inventory

The Intermountain Station, headquartered in Ogden, Utah, is one of eight regional experiment stations charged with providing scientific knowledge to help resource managers meet human needs and protect forest and range ecosystems.

The Intermountain Station includes the States of Montana, Idaho, Utah, Nevada, and western Wyoming. About 231 million acres, or 85 percent, of the land area in the Station territory are classified as forest and rangeland. These lands include grasslands, deserts, shrublands, alpine areas, and well-stocked forests. They supply fiber for forest industries; minerals for energy and industrial development; and water for domestic and industrial consumption. They also provide recreation opportunities for millions of visitors each year.

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Moscow, Idaho (in cooperation with the University of Idaho)

Provo, Utah (in cooperation with Brigham Young University)

Reno, Nevada (in cooperation with the University of Nevada)

United States
Department of
Agriculture

Forest Service

**Intermountain
Forest and Range
Experiment Station**

General Technical
Report INT-118

September 1982

Estimating Production Rates and Operating Costs of Timber Harvesting Equipment in the Northern Rockies

Rulon B. Gardner

THE AUTHOR

RULON B. GARDNER was principal research engineer, located at the Intermountain Station's Forestry Sciences Laboratory in Bozeman, Mont., until his retirement in 1979. Mr. Gardner conducted logging systems research studies for 18 years, 15 years of which were spent in the Rocky Mountain area.

RESEARCH SUMMARY

In recent years, logging has become more difficult and expensive because of decreased accessibility, smaller timber, and the need for more expensive specialized equipment. The Intermountain Station has conducted numerous studies to evaluate costs, equipment, and methods for logging under various conditions, treatments, silvicultural and environmental objectives in the Northern Rocky Mountains.

This report summarizes studies completed in the past decade for most types of equipment that have been used or tried in the Northern Rocky Mountain area. The report provides descriptions of equipment and logging methods, and equations, nomographs, tables, and production data for estimating system productivity. Methods for designing systems, computing costs, and estimating fuel requirements are also included.

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INTRODUCTION

Research conducted by the Intermountain Forest and Range Experiment Station during the past 15 years has studied a wide variety of logging systems and equipment. Information from these studies identifies the principal factors affecting productivity of the systems and equipment used in the Northern Rockies and provides a basis for predicting productivity. This paper summarizes the information available and provides published references related to this subject.

The study of logging systems has proved to be difficult primarily because of the many different variables influencing production and the analyst's lack of control over the operation. Logging is carried out under conditions of continued change in the variables affecting production, such as timber size and stand density, terrain, soil, and weather. This makes it difficult to evaluate effects of the variables.

Another complication is the analyst's lack of control of the operation. Operator skill and motivation also affect the logging operation. Despite these obstacles, past studies have produced data useful for analyzing and predicting productivity of systems and equipment under a wide range of conditions.

How are these studies conducted and how can they be used effectively? The objective of any analyst is to be able to represent the functioning of the system studied by means of a model or group of models. Usually logging subsystems are studied independently—that is, felling, or felling and bucking, skidding or yarding, loading, and hauling. Subsystems can then be fitted into a total harvesting system by techniques such as simulation.

Subsystem production is usually expressed by regression equations derived from the study data. The subsystem regression equations can be used by logging system planners to predict equipment productivity under various conditions, to help estimate the cost of logging. Simulation techniques, as suggested, can be used to help select total system designs.

The data usually collected for analysis are equipment operating times, quantities (volume or weight) of timber removed, and measures of variables potentially affecting production. These data are then analyzed to determine the principal variables influencing production.

TIMBER HARVESTING EQUIPMENT, SYSTEMS, AND PRODUCTIVITY

A nearly full range of equipment types found throughout the United States and abroad is being used in the Northern Rockies, with the exception of some of the newer processors. Most of this equipment has been the subject of study and analysis by the Intermountain Station engineering research work unit. (Data collection and analysis methods are discussed in the appendix.)

To enhance usefulness, production equations are given in horsepower or weight classifications for equipment types whenever possible. Symbols for variables in the equations are shown in table 1.

Some of the variables have been transformed as shown in the equations. The dependent variable is turn time in minutes. Turn time can be converted to production using log size, volume, or weight; whatever is needed for conversion. Information from published sources is referenced. Graphs or tables for solving the equations are included with instructions for their use.

Table 1.--Symbols for regression equations

Symbol	Definitions	Units
DI	Skidding distance with load	ft or m
DITOT	Total distance traveled by the skidder	ft or m
LD	Lateral skidding distance	ft or m
SL	Slope	percent
WT	Weight	lb or kg
NL	Number of logs	each
VOL	Volume	M bd. ft., ft^3, M^3
TT	Turn time	min
LN	Natural log	

Following are instructions for use of the nomographs and tables used in this report:

Nomographs:

- Three variables. From the example for the Idaho jammer in figure 8, use a straightedge to connect the variables of slope (SL) and distance (DI) and read the turn time (TT) directly from the scale (11.8 min).
- Four variables. From the example for 25-59 DBHP tracked skidders in figure 3a, use two straightedge materials (two plastic rulers are best) to solve for turn time. Connect the variable on the left scale (SL) with the next variable to the right (NL) to find the index point on the "q" scale. Then connect this point with the variable scale on the right side (DI) of the figure. Where this line intersects the TT scale, the turn time (31.0 min) is read.

Tables:

- For an example use table 2 (running skyline, shelterwood, uphill). Enter Matrix A with a lateral distance of 40 ft (12.2 m) and a skyline distance of 525 ft (160.0 m) to obtain the value of 5.808. Enter Matrix B with weight of 2,990 lb (1 356 kg) to obtain the value of 1.027. Multiply the value from table 2 Matrix A, by the value from table 2 Matrix B, (5.808 x 1.027) to obtain the turn time of 5.96 min.

Ground Skidding Equipment

Prior to World War II, ground skidding was the most common method for skidding logs in the Rocky Mountain area. This was primarily because good timber was still available on easy-to-log, gentle terrain.

Horse logging, although still practiced in a few areas in eastern Canada and the United States, is seldom used today. Track-laying vehicles, mostly those built for the construction industry and adapted to logging, and articulated rubber-tired skidders perform virtually all of the ground skidding.

Rubber-tired skidders were not used extensively in the Rocky Mountain area until the past 8 or 10 years. However, they are being used more often now, especially for skidding on slopes less than about 35 percent and for the longer skidding distances.

The skidding capacity of all the equipment is dependent on its drawbar horsepower, weight, and traction obtainable under the ground conditions encountered in logging.

Tracked Skidders

Track-laying (crawler) tractors are of two general types: the standard construction type with steel tracks shown in figure 1, and the high-flotation, rubber-mounted type in figure 2. Size classes used for logging range from approximately 8,000 lb (3 885 kg)-25 drawbar horsepower (DBHP) to 45,000 lb (19 600 kg)-130 DBHP. Most crawler skidders are equipped with integral arches and chokers; however, some have used pans for skidding.

Figure 1.--Conventional tractor skidder suited to moderately steep terrain.

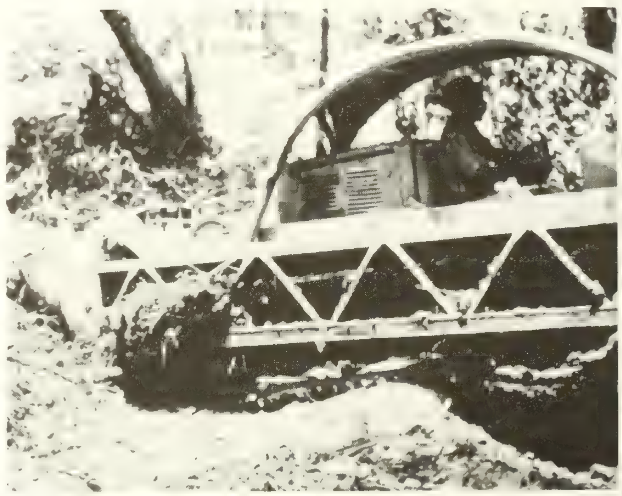

Figure 2.--High-flotation tracked skidder.

Turn times for skidders are predicted using equations lerived from logging studies.

The equations and nomographs for solving nem for tracked skidders follow (fig. 3a, 3b, 3c):

racked skidders
vith drawbar horse-
ower ratings of 25-59
urn time in minutes 14.12
+0.1603 X SL
+ .0108 X DI
+1.470 X NL

he degree of variation
xplained by the
ariables in this
quation is .... 53 percent

---

racked skidders
vith drawbar horse-
ower ratings of 60-89
urn time in minutes 4.85
+0.1258 X SL
+ .0054 X DI
+1.3308 X NL

he degree of variation
xplained by the
ariables in this
quation is .... 20 percent

---

racked skidders
ith drawbar horse-
ower ratings of 90-130
urn time in minutes 14.0
-0.1446 X SL
+ .0714 X DI
+ .3360 X NL

he degree of variation
xplained by the
ariables in this
quation is .... 35 percent
ublication: Brown (1967)

igure 4.--Articulated rubber-tired skidder with integral arch.

Figure 5.--Articulated grapple rubber-tired skidder.

Rubber-Tired Skidders

All of the rubber-tired skidders in use today are fully articulated and are used with chokers and an integral arch (fig. 4) or a grapple (fig. 5). Size classes range from approximately 10,000 lb (4 235 kg)-55 brake horsepower (BHP) to 18,500 lb (5 633 kg)-150 BHP.

The equation and nomographs follow for rubber-tired skidders with an integral arch and chokers (fig. 6a, 6b, 6c).

Rubber-tired skidders
with brake horsepower
ratings of 70-90
Turn time in minutes 6.58
-0.368 X NL
+ .00065 X WT
+ .0168 X DITOT

Degree of variation
explained by the equa-
tion .... 55 percent

Rubber-tired skidders
with brake horsepower
ratings of 110-150
Turn time in minutes .... -0.1971
+1.1287 X NL
+ .0045 X VOL
+ .0063 X DITOT

Degree of variation
explained by the equa-
tion .... 84 percent

Rubber-tired skidders
with brake horsepower
ratings of 70-150
Turn time in minutes 2.57
+0.8228 X NL
+ .0054 X VOL
+ .0078 X DITOT

Degree of variation
explained by the equa-
tion .... 76 percent
Publication: Gardner (1979)

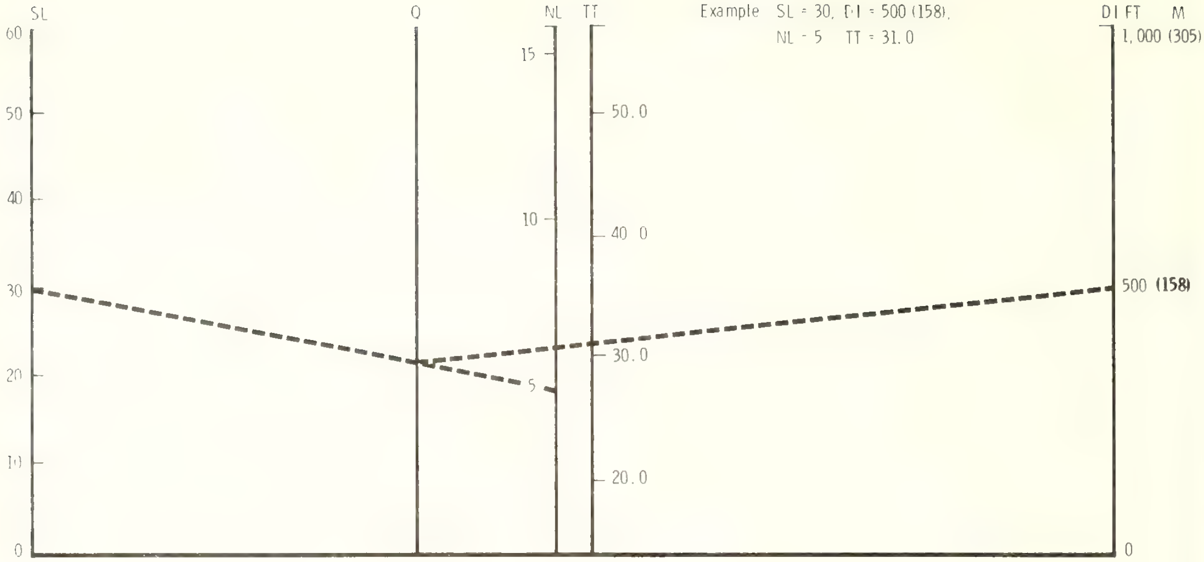

Figure 3a.--Performance nomograph, tracked skidders: 25-59 DBHP.

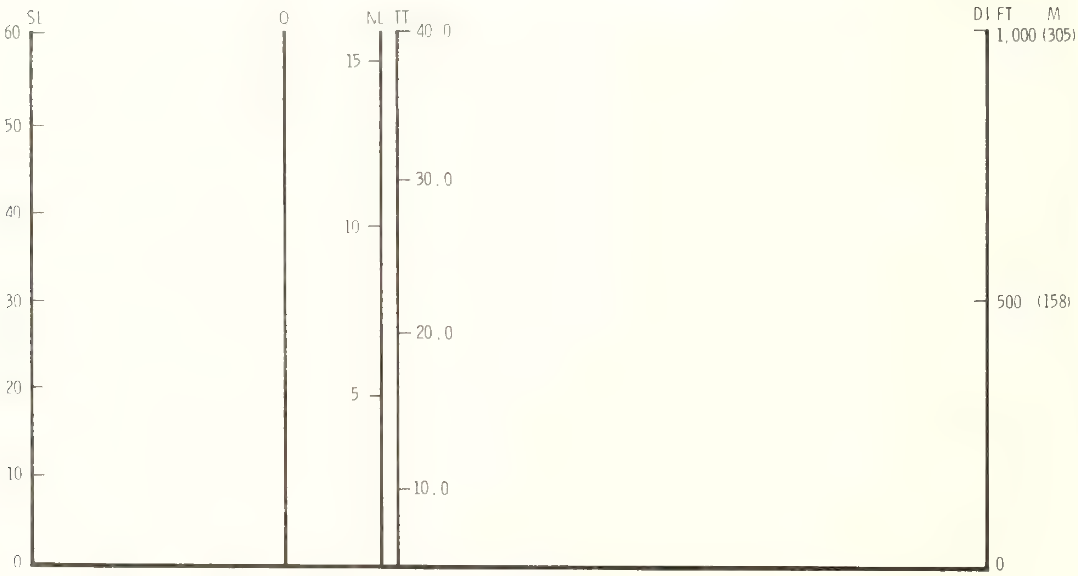

Figure 3b.--Performance nomograph, tracked skidders: 60-89 DBHP.

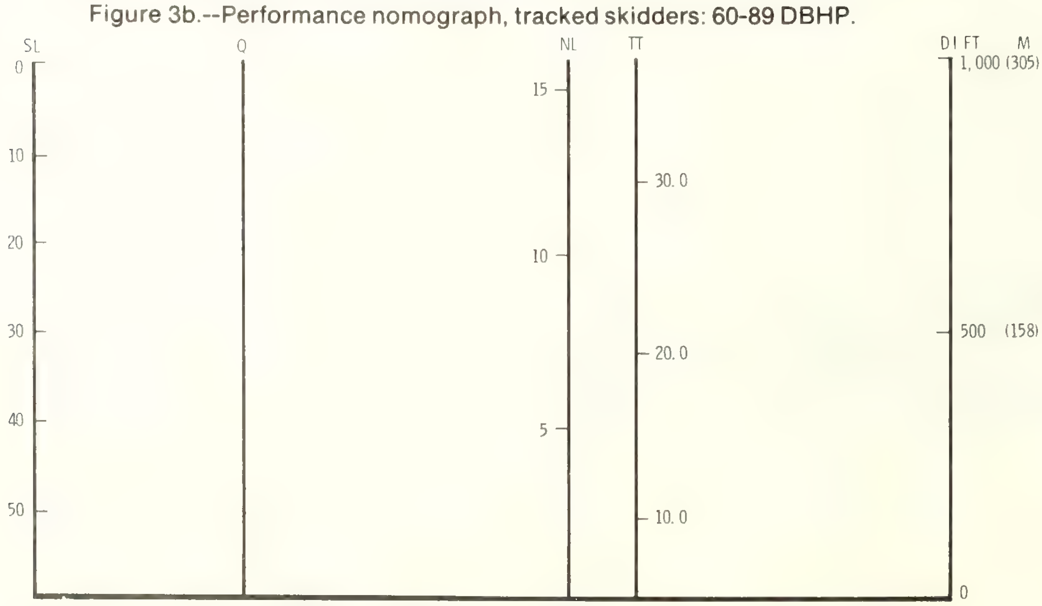

Figure 3c.--Performance nomograph, tracked skidders: 90-130 DBHP.

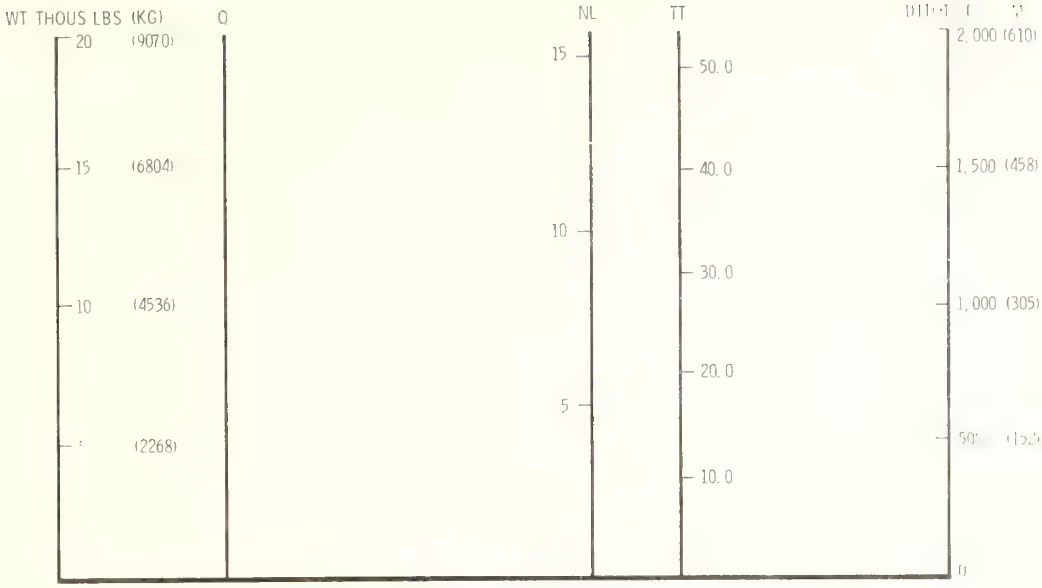

Figure 6a.--Performance nomograph, rubber-tired skidders: 70-90 BHP.

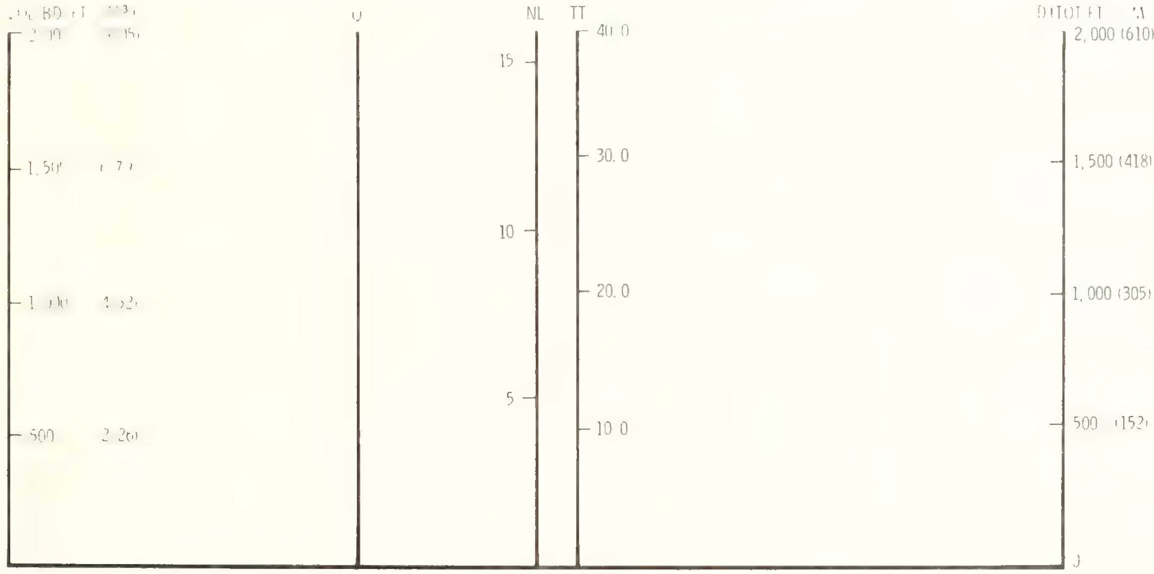

Figure 6b.--Performance nomograph, rubber-tired skidders: 110-150 BHP.

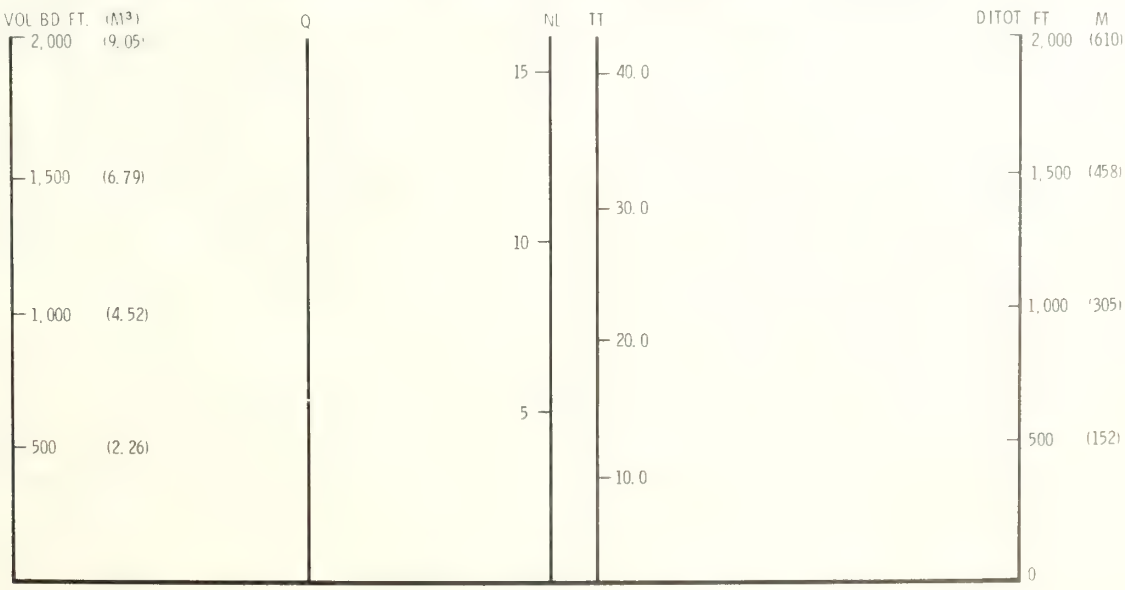

Figure 6c.--Performance nomograph, rubber-tired skidders: 70-150 BHP.

Cable Skidding or Yarding Equipment

Since the mid-1940's, Idaho jammers and high-lead systems have been used in the Rocky Mountain area to log slopes too steep for crawler tractors. Skyline systems, on the other hand, have come into use within the past 10 years or so.

Cable skidding can be classified as jammer, high-lead, and skyline. Jammer and high-lead systems do not require deflection or a carriage (both are required for skyline systems). Logs are ground skidded to the yarder by chokers attached to the butt rigging. Skyline systems partly or fully suspend the logs during yarding.

Idaho Jammer

An Idaho jammer (fig. 7) can be assembled from almost any prime mover on which a boom or spar and two drums can be mounted. Everything from a surplus Army truck to a 50,000-lb (21 800-kg) crawler tractor has been converted to an Idaho jammer. The size of the equipment and the rigging determine maximum load sizes and skidding distances. However, skidding distances of more than 300-400 ft (91-122 m) are seldom used because of the tendency of logs to "hang up" during skidding.

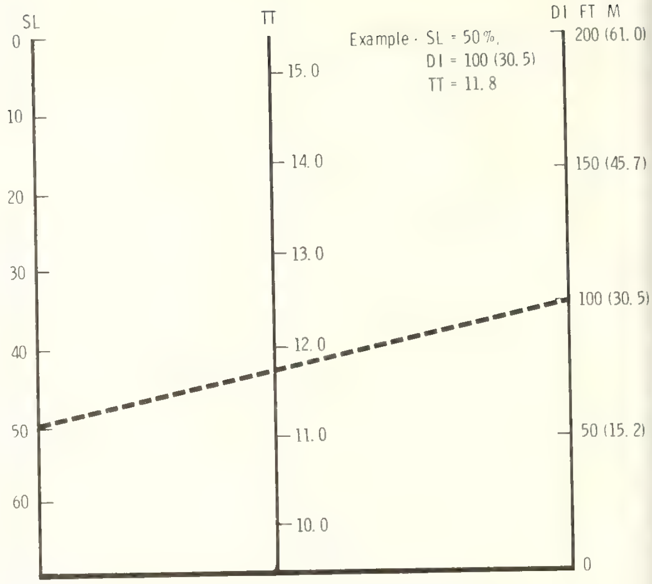

Figure 8.--Performance nomograph, Idaho jammer.

Figure 7.--Idaho jammer built on heavy truck chassis.

Jammer data are from two operations. Both yarded one log per cycle, with an average log size of 237 bd.ft. (1.1m^3) at an average distance of 57 ft (17.3 m).

An equation and nomograph follow (fig. 8):

Turn time in minutes .... 12.774 -0.0468 X SL + .0132 X DI

Degree of variation explained by the equation .... 11 percent

Publication: Brown (1967)

High Lead

High-lead yarding (fig. 9) is generally done with portable tower or boom and a double-drum yarder. Mai and haulback lines vary in size from five-eights inc (1.6 cm) to 1-1/4 inches (3.2 cm) for the larger systems Distances up to about 800 ft (243 m) are loggable with thes systems, depending on the terrain, timber stand, an cutting system. Yarding distances of 400-500 ft (12 152 m) are most common.

Figure 9.--High lead yarder.

The high-lead operations averaged 4.0 logs per load, vith an average log size of 150 bd.ft. (0.68 m^3) and an werage yarding distance of 518 ft (157 m). Following is an equation and accompanying nomograph (fig. 10):

Turn time in minutes	26.06 +0.05718 X SL + .04638 X NL
Degree of variation explained by the equation	12 percent

Publication: Brown (1967)

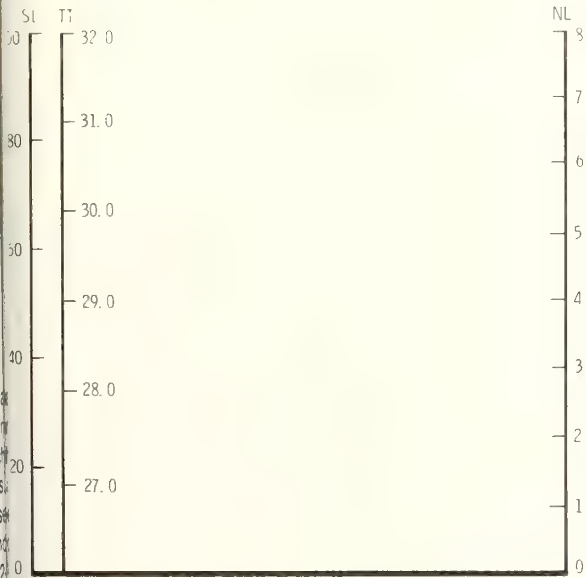

Figure 10.--Performance nomograph, high lead yarder.

Skyline Yarders

The skyline equations are for running and live skylines or three silvicultural prescriptions and for uphill and downhill yarding.

Live skyline.--The live skyline (fig. 11) uses a gravity carriage and is often rigged with a slack-pulling line to pull out main line for lateral skidding. Yarder and drum sizes determine cable sizes that in turn determine yarding distances and load sizes.

Distances of up to 2,000 ft (610 m) have been logged when enough deflection is available; however, most yarding distances are 1,000 ft (305 m) or less.

Running skyline.--In a running skyline (fig. 12), the carriage runs on the haulback line and is usually a slack-pulling carriage controlled by the slack-pulling line. Yarding distances like the live skyline are dependent on deflection, the equipment size, and yarding drums. Yarding distances of 1,000-1,200 ft (305-366 m) are near maximum for most running skyline systems.

The equations for live and running skylines are a function of the natural logarithms. The natural logarithms can be obtained from tables. However, the equations can be more easily solved using tables 2 through 8.

Figure 11.--Live skyline yarder.

Figure 12.--Running skyline yarder.

Table 2.--Turn time prediction factors, running skyline, shelterwood, uphill (numbers in italics are used in instructions, page 2)

Matrix A

Skyline distance	Lateral distance, ft (m)										
	0	**10 (3.0)**	**20 (6.1)**	**30 (9.1)**	**40 (12.2)**	**50 (15.2)**	**60 (18.3)**	**70 (21.3)**	**80 (24.4)**	**90 (27.4)**	**100 (30.5)**
Feet (Meters)											
25 (7.6)	4.350	4.400	4.451	4.502	4.554	4.606	4.660	4.713	4.767	4.822	4.878
125 (38.1)	4.567	4.620	4.673	4.727	4.781	4.836	4.892	4.948	5.005	5.063	5.121
225 (68.6)	4.795	4.850	4.906	4.962	5.019	5.077	5.136	5.195	5.255	5.315	5.376
325 (99.1)	5.034	5.092	5.150	5.210	5.270	5.330	5.392	5.454	5.517	5.580	5.644
425 (130.0)	5.285	5.346	5.407	5.469	5.532	5.596	5.661	5.726	5.792	5.858	5.926
525 (160.0)	5.548	5.612	5.677	5.742	*5.808*	5.875	5.943	6.011	6.080	6.150	6.221
625 (190.0)	5.825	5.892	5.960	6.028	6.098	6.168	6.239	6.311	6.384	6.457	6.531
725 (221.0)	6.115	6.186	6.257	6.329	6.402	6.476	6.550	6.626	6.702	6.779	6.857
825 (252.0)	6.420	6.494	6.569	6.645	6.721	6.798	6.877	6.956	7.036	7.117	7.199
925 (282.0)	6.740	6.818	6.896	6.976	7.056	7.137	7.220	7.303	7.387	7.472	7.558
1,025 (312.0)	7.076	7.158	7.240	7.324	7.408	7.493	7.580	7.667	7.755	7.844	7.935
1,125 (343.0)	7.429	7.515	7.601	7.689	7.777	7.867	7.957	8.049	8.142	8.236	8.330

Matrix B

Weight, lb (kg)										
30 (13.6)	**1,510 (685)**	***2,990* (1 356)**	**4,470 (2 028)**	**5,950 (2 699)**	**7,430 (3 370)**	**8,910 (4 042)**	**10,390 (4 713)**	**11,870 (5 384)**	**13,350 (6 056)**	**14,830 (6 729)**
1.000	1.014	*1.027*	1.041	1.055	1.069	1.083	1.098	1.112	1.127	1.142

Table 3.--Turn time predication factors, running skyline, shelterwood, downhill

	Matrix A Lateral distance, ft (m)										
Number of logs	**0**	**10 (3.0)**	**20 (6.1)**	**30 (9.1)**	**40 (12.2)**	**50 (15.2)**	**60 (18.3)**	**70 (21.3)**	**80 (24.4)**	**90 (27.4)**	**100 (30.5)**
1	1.968	1.972	1.977	1.982	1.987	1.991	1.996	2.001	2.006	2.011	2.015
2	1.968	1.977	1.987	1.996	2.006	2.015	2.025	2.035	2.045	2.054	2.064
3	1.968	1.982	1.996	2.011	2.025	2.040	2.054	2.069	2.084	2.099	2.115
4	1.968	1.987	2.006	2.025	2.045	2.064	2.084	2.104	2.125	2.145	2.166
5	1.968	1.991	2.015	2.040	2.064	2.089	2.115	2.140	2.166	2.192	2.218
6	1.968	1.996	2.025	2.054	2.084	2.115	2.145	2.176	2.208	2.240	2.272
7	1.968	2.001	2.035	2.069	2.104	2.140	2.176	2.213	2.251	2.289	2.328
8	1.968	2.006	2.045	2.084	2.125	2.166	2.208	2.251	2.294	2.339	2.384
9	1.968	2.011	2.054	2.099	2.145	2.192	2.240	2.289	2.339	2.390	2.442
10	1.968	2.015	2.064	2.115	2.166	2.218	2.272	2.328	2.384	2.442	2.501

	Matrix B Volume, bd.ft. (m^3)										
Slope (percent)	**5 (0.02)**	**30 (0.14)**	**55 (0.25)**	**80 (0.36)**	**105 (0.48)**	**130 (0.59)**	**155 (0.70)**	**180 (0.82)**	**205 (0.93)**	**230 (1.04)**	**255 (1.16)**
-30	1.005	1.029	1.054	1.080	1.106	1.133	1.160	1.189	1.218	1.247	1.277
-25	1.004	1.024	1.045	1.066	1.086	1.110	1.132	1.155	1.178	1.202	1.226
-20	1.003	1.019	1.036	1.053	1.070	1.087	1.104	1.122	1.140	1.159	1.177
-15	1.002	1.015	1.027	1.039	1.052	1.064	1.077	1.090	1.103	1.117	1.130
-10	1.002	1.010	1.018	1.026	1.034	1.042	1.051	1.059	1.068	1.076	1.085
- 5	1.001	1.005	1.009	1.013	1.017	1.021	1.025	1.029	1.033	1.037	1.042
0	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
5	.999	.995	.991	.987	.983	.979	.976	972	.968	.964	.960
10	.998	.990	.983	.975	.967	.959	.952	.944	.937	.929	.922
15	.998	.986	.974	.962	.951	.940	.928	.917	.906	.895	.885
20	.997	.981	.965	.950	.935	.920	.906	.891	.877	.863	.849

	Matrix C Distance, ft (m)										
	25 (7.6)	**105 (32.0)**	**185 (56.4)**	**265 (80.8)**	**345 (105)**	**425 (130)**	**505 (154)**	**585 (178)**	**665 (204)**	**745 (227)**	**825 (251)**
	1.531	1.851	1.995	2.093	2.167	2.228	2.279	2.324	2.364	2.399	2.432

Table 4.--Turn time predication factors, running skyline, group selection, uphill

Matrix A

Number of logs	Weight, lb (kg) 200 (90.7)	1,200 (544)	2,200 (998)	3,200 (1 452)	4,200 (1 905)	5,200 (2 359)	6,200 (2 823)	7,200 (3 266)	8,200 (3 720)	9,200 (4 173)	10,200 (4 627)
1	1.788	1.795	1.802	1.809	1.817	1.824	1.831	1.838	1.846	1.853	1.861
2	1.789	1.804	1.818	1.833	1.847	1.862	1.877	1.892	1.907	1.923	1.938
3	1.791	1.812	1.834	1.856	1.879	1.901	1.924	1.948	1.971	1.995	2.019
4	1.792	1.821	1.850	1.880	1.910	1.941	1.973	2.004	2.037	2.070	2.103
5	1.793	1.830	1.867	1.904	1.943	1.982	2.022	2.063	2.105	2.147	2.191
6	1.795	1.838	1.883	1.928	1.976	2.024	2.073	2.123	2.175	2.228	2.282
7	1.796	1.847	1.900	1.954	2.009	2.066	2.125	2.185	2.248	2.311	2.377
8	1.798	1.856	1.917	1.979	2.043	2.110	2.178	2.249	2.323	2.398	2.476
9	1.799	1.865	1.934	2.004	2.078	2.154	2.233	2.315	2.400	2.488	2.579
10	1.801	1.874	1.951	2.030	2.113	2.199	2.289	2.383	2.480	2.581	2.687

Matrix B

Slope (percent)	Lateral distance, ft (m) 0	10 (3.0)	20 (6.1)	30 (9.1)	40 (12.2)	50 (15.2)	60 (18.3)	70 (21.3)	80 (24.4)	90 (27.4)	100 (30.5)
22	0.935	0.953	0.971	0.990	1.009	1.029	1.049	1.070	1.090	1.112	1.133
27	.920	.938	.956	.975	.994	1.013	1.033	1.053	1.074	1.095	1.116
32	.906	.924	.942	.960	.979	.998	1.017	1.037	1.057	1.078	1.099
37	.892	.910	.982	.946	.964	.983	1.002	1.021	1.041	1.062	1.082
42	.879	.896	.913	.931	.949	.968	.987	1.006	1.025	1.045	1.066
47	.865	.882	.899	.917	.935	.953	.972	.990	1.010	1.029	1.049
52	.852	.869	.886	.903	.921	.938	.957	.975	.994	1.014	1.033
57	.839	.856	.872	.889	.906	.924	.942	.960	.979	.998	1.018
62	.826	.842	.859	.876	.893	.910	.928	.946	.964	.983	1.002
67	.814	.830	846	.862	.879	.896	.914	.931	.949	.968	.987
72	.801	.817	.833	.849	.866	.882	.900	.917	.935	.953	.972

Matrix C

	Distance, ft (m) 50 (15.2)	170 (51.8)	290 (88.4)	410 (125)	530 (162)	650 (198)	770 (235)	890 (271)	1,010 (308)	1,130 (344)	1,250 (381)
	2.118	2.678	2.967	3.171	3.331	3.464	3.579	3.679	3.770	3.852	3.927

Table 5.--Turn time predication factors, running skyline, group selection, downhill

	Matrix A										
	Weight, lb (kg)										
Number of logs	**250 (113)**	**1,150 (526)**	**2,050 (930)**	**2,950 (1 338)**	**3,850 (1 746)**	**4,750 (2 155)**	**5,650 (2 563)**	**6,550 (2 971)**	**7,450 (3 379)**	**8,350 (3 788)**	**9,250 (4 196)**
2	0.503	0.506	0.509	0.513	0.516	0.519	0.522	0.526	0.529	0.533	0.536
3	503	.508	513	.518	.523	.528	.533	.538	.543	549	.554
4	504	.510	.517	.523	.530	.537	544	.551	.558	.565	.572
5	.504	.512	.521	529	537	.546	555	.564	.573	.582	.591
6	505	.514	.524	534	.545	.555	.566	.577	588	599	.611
7	.505	.517	.528	.540	.552	565	.577	.590	.604	.617	.631
8	.506	.519	.532	.546	.560	.574	.589	.604	.620	.636	.652
9	.506	.521	.536	.551	.567	.584	.601	.618	.636	.655	.674
10	.506	.523	.540	.557	.575	.594	.613	.633	.653	.674	696
11	.507	.525	.544	.563	.583	.604	.625	.648	.671	.695	.719
	Matrix B										
	Distance, ft (m)										
Lateral distance	**180 (54.9)**	**240 (73.2)**	**300 (91.4)**	**360 (110)**	**420 (128)**	**480 (146)**	**540 (165)**	**600 (183)**	**660 (201)**	**720 (219)**	**780 (238)**
Feet (Meters)											
10 (3.0)	5.934	6.540	7.052	7.499	7.900	8.265	8.600	8.912	9.204	9.478	9.738
20 (6.1)	6.093	6.715	7.241	7.701	8.112	8.487	8.831	9.151	9.450	9.732	9.999
30 (9.1)	6.257	6.895	7.435	7.907	8.330	8.714	9.068	9.396	9.704	9.993	10.267
40 (12.2)	6.424	7.080	7.634	8.119	8.553	8.948	9.311	9.649	9.964	10.261	10.543
50 (15.2)	6.597	7.270	7.839	8.337	8.783	9.188	9.561	9.907	10.232	10.537	10.826
60 (18.3)	6.774	7.465	8.049	8.561	9.018	9.434	9.817	10.173	10.506	10.819	11.116
70 (21.3)	6.955	7.665	8.265	8.790	9.260	9.688	10.081	10.446	10.788	11.110	11.414
80 (24.4)	7.142	7.871	8.487	9.026	9.509	9.947	10.351	10.726	11.077	11.408	11.720
90 (27.4)	7.333	8.082	8.715	9.268	9.764	10.214	10.629	11.014	11.374	11.714	12.035
100 (30.5)	7.530	8.299	8.948	9.517	10.026	10.488	10.914	11.309	11.679	12.028	12.357

Table 6.--Turn time predication factors, running skyline, clearcut, uphill

Matrix A

Distance	Volume, bd.ft. (m^3) 5 (0.02)	25 (0.11)	45 (0.20)	65 (0.29)	85 (0.38)	105 (0.48)	125 (0.57)	145 (0.66)	165 (0.75)	185 (0.84)	205 (0.93)
Feet (Meters)											
60 (18.3)	3.172	3.212	3.252	3.293	3.334	3.375	3.417	3.460	3.503	3.579	3.591
145 (44.2)	3.440	3.483	3.527	3.571	3.615	3.660	3.706	3.752	3.799	3.846	3.894
230 (70.1)	3.701	3.747	3.794	3.842	3.889	3.938	3.987	4.037	4.087	4.138	4.190
315 (96.0)	3.951	4.000	4.050	4.101	4.152	4.204	4.256	4.309	4.363	4.417	4.473
400 (122)	4.184	4.237	4.289	4.343	4.397	4.452	4.508	4.564	4.621	4.678	4.737
485 (148)	4.397	4.452	4.507	4.563	4.620	4.678	4.736	4.796	4.855	4.916	4.977
570 (174)	4.584	4.641	4.699	4.758	4.817	4.877	4.938	4.999	5.062	5.125	5.189
655 (200)	4.741	4.800	4.860	4.921	4.982	5.045	5.108	5.171	5.236	5.301	5.367
740 (226)	4.866	4.926	4.988	5.050	5.113	5.177	5.242	5.307	5.373	5.440	5.508
825 (251)	4.954	5.016	5.079	5.142	5.206	5.271	5.337	5.403	5.471	5.539	5.608
910 (277)	5.005	5.067	5.130	5.194	5.259	5.325	5.391	5.459	5.527	5.596	5.665

Matrix B

Slope (percent)	Lateral distance, ft (m) 0	10 (3.0)	20 (6.1)	30 (9.1)	40 (12.2)	50 (15.2)	60 (18.3)	70 (21.3)	80 (24.4)	90 (27.4)	100 (30.5)
20	1.000	1.009	1.017	1.026	1.035	1.044	1.053	1.062	1.071	1.080	1.090
25	1.000	1.011	1.022	1.033	1.044	1.055	1.067	1.078	1.090	1.102	1.113
30	1.000	1.013	1.026	1.039	1.053	1.067	1.080	1.095	1.109	1.123	1.138
35	1.000	1.015	1.031	1.046	1.062	1.078	1.095	1.111	1.128	1.145	1.162
40	1.000	1.017	1.035	1.053	1.071	1.090	1.109	1.128	1.148	1.167	1.188
45	1.000	1.020	1.039	1.060	1.080	1.102	1.123	1.145	1.167	1.190	1.213
50	1.000	1.022	1.044	1.067	1.090	1.113	1.138	1.162	1.188	1.213	1.240
55	1.000	1.024	1.048	1.074	1.099	1.126	1.152	1.180	1.208	1.237	1.267
60	1.000	1.026	1.053	1.080	1.109	1.138	1.167	1.198	1.229	1.261	1.294

Matrix C

	Number of logs 1	2	3	4	5	6	7	8	9	10
	1.020	1.040	1.061	1.081	1.103	1.125	1.147	1.169	1.193	1.261

Table 7.--Turn time predication factors, live skyline, group selection, uphill

	Matrix A										
	Lateral distance, ft (m)										
Slope (percent)	0	10 (3.0)	20 (6.1)	30 (9.1)	40 (12.2)	50 (15.2)	60 (18.3)	70 (21.3)	80 (24.4)	90 (27.4)	100 (30.5)
40	4.189	4.262	4.336	4.411	4.488	4.566	4.645	4.726	4.808	4.891	4.976
45	3.995	4.064	4.135	4.207	4.280	4.354	4.430	4.506	4.585	4.664	4.745
50	3.810	3.876	3.943	4.012	4.081	4.152	4.224	4.297	4.372	4.448	4.525
55	3.633	3.696	3.760	3.825	3.892	3.959	4.028	4.098	4.169	4.242	4.315
60	3.464	3.525	3.586	3.648	3.711	3.776	3.841	3.908	3.976	4.045	4.115
65	3.304	3.361	3.419	3.479	3.539	3.601	3.663	3.727	3.791	3.857	3.924
70	3.150	3.205	3.261	3.317	3.375	3.434	3.493	3.554	3.615	3.678	3.742
	Matrix B										
	Weight, lb (kg)										
Number of logs	75 (34.0)	875 (397)	1,675 (760)	2,475 (1 123)	3,275 (1 486)	4,075 (1 848)	4,875 (2 211)	5,675 (2 574)	6,475 (2 937)	7,275 (3 300)	8,075 (3 663)
1	1.000	1.002	1.005	1.007	1.009	1.011	1.014	1.016	1.018	1.020	1.023
2	1.000	1.005	1.009	1.014	1.018	1.023	1.027	1.032	1.037	1.041	1.046
3	1.001	1.007	1.014	1.021	1.028	1.034	1.041	1.048	1.055	1.062	1.069
4	1.001	1.010	1.019	1.028	1.037	1.046	1.056	1.065	1.074	1.084	1.094
5	1.001	1.012	1.023	1.035	1.046	1.058	1.070	1.082	1.094	1.106	1.118
6	1.001	1.015	1.028	1.042	1.056	1.070	1.084	1.099	1.114	1.129	1.144
7	1 001	1.017	1.033	1.049	1.066	1.082	1.099	1.116	1.134	1.152	1.170
8	1.002	1.020	1.038	1.056	1.075	1.095	1.114	1.134	1.154	1.175	1.196
9	1.002	1.022	1.043	1.064	1.085	1.107	1.129	1.152	1.175	1.199	1.223
10	1.002	1.025	1.048	1.071	1.095	1.120	1.145	1.170	1.197	1.224	1.251
11	1.002	1.027	1.052	1.078	1.105	1.132	1.160	1.189	1.218	1.248	1.279
12	1.002	1.030	1.057	1.086	1.115	1.145	1.176	1.208	1.240	1.274	1.308
	Matrix C										
	Distance, ft (kg)										
	50 (15.2)	125 (38.1)	200 (61.0)	275 (83.8)	350 (107)	425 (130)	500 (152)	575 (175)	650 (198)	725 (221)	800 (244)
	1.048	1.125	1.207	1.295	1.390	1.491	1.600	1.717	1.842	1.977	2.121

Table 8.--Turn time prediction factors, live skyline, clearcut, uphill

ft (m) Distance	Matrix A Lateral distance, ft (m) 0	10 (3.0)	20 (6.1)	30 (9.1)	40 (12.2)	50 (15.2)	60 (18.3)	70 (21.3)	80 (24.4)	90 (27.4)	100 (30.5)
Feet (Meters)											
10 (3.0)	6.790	6.935	7.084	7.236	7.390	7.549	7.710	7.875	8.044	8.216	8.392
90 (27.4)	7.093	7.245	7.400	7.558	7.720	7.885	8.054	8.226	8.402	8.582	8.766
170 (51.8)	7.409	7.567	7.729	7.895	8.064	8.236	8.413	8.593	8.777	8.965	9.157
250 (76.2)	7.739	7.905	8.074	8.247	8.423	8.604	8.788	8.976	9.168	9.364	9.565
330 (101)	8.084	8.257	8.434	8.614	8.799	8.987	9.179	9.376	9.577	9.781	9.991
410 (125)	8.444	8.625	8.810	8.998	9.191	9.387	9.588	9.794	10.003	10.217	10.436
490 (149)	8.820	9.009	9.202	9.399	9.600	9.806	10.016	10.230	10.449	10.673	10.901
570 (174)	9.214	9.411	9.612	9.818	10.028	10.243	10.462	10.686	10.915	11.148	11.387
650 (198)	9.624	9.830	10.041	10.255	10.475	10.699	10.928	11.162	11.401	11.645	11.894
730 (223)	10.053	10.268	10.488	10.713	10.942	11.176	11.415	11.660	11.908	12.164	12.425
810 (247)	10.501	10.726	10.955	11.190	11.429	11.674	11.924	12.179	12.440	12.706	12.978
890 (271)	10.969	11.204	11.444	11.689	11.939	12.194	12.455	12.722	12.994	13.272	13.557
970 (296)	11.458	11.703	11.954	12.209	12.471	12.738	13.010	13.289	13.573	13.864	14.161

Slope (percent)	Matrix B Number of logs 1	2	3	4	5	6	7	8	9	10
45	0.486	0.598	0.641	0.644	0.678	0.687	0.694	0.699	0.703	0.707
50	.470	.578	.620	.642	.655	.664	.671	.676	.680	.683
55	.454	.559	.599	.620	.633	.642	.648	.653	.657	.660
60	.439	.540	.579	.599	.612	.621	.627	.631	.635	.638
65	.424	.522	.560	.579	.592	.600	.606	.610	.614	.617
70	.410	.505	.541	.560	.572	.580	.586	.590	.593	.596

Running skyline, shelterwood cut, logging .... Uphill
Natural log of turn time
in minutes ....

$$\begin{aligned} &1.45805\\ &+ .0004865 \times DI\\ &+ .001145 \times LD\\ &+ .00000896 \times W \end{aligned}$$

Degree of variation explained by
equation .... 34 percent

Running skyline, shelterwood cut,
logging .... Downhill
Natural log of turn time
in minutes ....

$$\begin{aligned} &0.676830\\ &+ .000240 \times NL \times LD\\ &+ .132343 \times LN(DI)\\ &- .000032 \times S \times V \end{aligned}$$

Degree of variation explained by
equation .... 44 percent

Running skyline, group
selection cut, logging .... Uphill
Natural log of turn time
in minutes ....

$$\begin{aligned} &0.580136\\ &- .003076 \times S\\ &+ .001928 \times LD\\ &+ .191832 \times LN(DI)\\ &+ .000004 \times NL \times W \end{aligned}$$

Degree of variation explained by
equation .... 68 percent

Running skyline, group
selection cut, logging .... Downhill
Natural log of turn time
in minutes ....

$$\begin{aligned} &-0.689134\\ &+ .002647 \times LD\\ &+ .337807 \times LN(DI)\\ &+ .00000354 \times NL \times W \end{aligned}$$

Degree of variation explained by
equation .... 32 percent

Running skyline,
clearcut logging .... Uphill
Natural log of turn time
in minutes ....

$$\begin{aligned} &1.089454\\ &+ .019567 \times NL\\ &+ .001065 \times DI\\ &+ .000617 \times V\\ &- .00000054 \times (DI)^2\\ &+ .000043 \times LD \times S \end{aligned}$$

Degree of variation explained by
equation .... 48 percent

Live skyline selection
cut, logging .... Uphill
Natural log of turn time
in minutes ....

$$\begin{aligned} &1.812551\\ &+ .000940 \times DI\\ &- .00950 \times S\\ &+ .001721 \times LD\\ &+ .000002773 \times NL \times W \end{aligned}$$

Degree of variation explained by
equation .... 42 percent

Live skyline,
clearcut logging .... Uphill
Natural log of turn time
in minutes ....

$$\begin{aligned} &1.910023\\ &+ .000545 \times DI\\ &- .006795 \times S\\ &+ .002118 \times LD\\ &- .4162 \times \left(\frac{1}{NL}\right) \end{aligned}$$

Degree of variation explained by
equation .... 41 percent
Publication: Gardner (1980)

Aerial Yarders

Helicopter logging experimentation began in the early 1960's, but helicopters were not used to any extent until the 1970's. Balloon logging experiments began a little later in the 1960's, and balloon logging is still largely experimental. Both systems are used primarily in steep country where roads are very costly to construct, are prohibited, or will severely damage the environment. More recently, both of these systems have also been used to log areas with unstable ground conditions, such as swampland in the South. The potential environmental advantages of these systems must be weighed against the increased cost of yarding and lack of access for timber stand improvement, fire, and other management tasks.

Balloon Yarding

In a balloon yarding system, the balloon (fig. 13) suspends the cables needed to control it and the logs. The balloon is rigged similar to a running skyline and uses an interlocking double-drum yarder, with main and haulback lines. In the balloon system, the choker lines are suspended from the butt rigging, which is attached to the drop line from the balloon. The balloon is positioned over the load by movement of the main and haulback lines; the choker line (can be varied in length) is brought to the ground by locking the main line drum and reeling in the haulback line. This process is reversed to suspend the load, and actuating the interlocking drum system brings the load to the landing.

The only operational system at the present time utilizes a Raven Industries 530,000 ft^3 (15 010 m^3), helium-filled, natural-shaped balloon (fig. 13) and a Washington Iron Works Aero Yarder, Model 608A. The main line drum has a capacity of 5,550 ft (1 672 m) of 1-inch (2.54-cm) cable, and the haulback drum, 7,000 ft (2 128 m) of 1-inch (2.54-cm) cable. Yarding distance depends on drum size, but is in the 3,000-4,000-ft (912-1 216-m) range.

Figure 13.--Natural-shaped logging balloon

The balloon data are for the only commercial balloon logging equipment available, discussed under Aerial Yarders. The equation for turn time in minutes is taken from Hartsog (1978):

Balloon logging,
selection cut .... Downhill
Turn time in minutes 3.43
+0.00391 X DI
+ .0036 X LD

Publication: Hartsog (1978)
See figure 14 for nomograph.

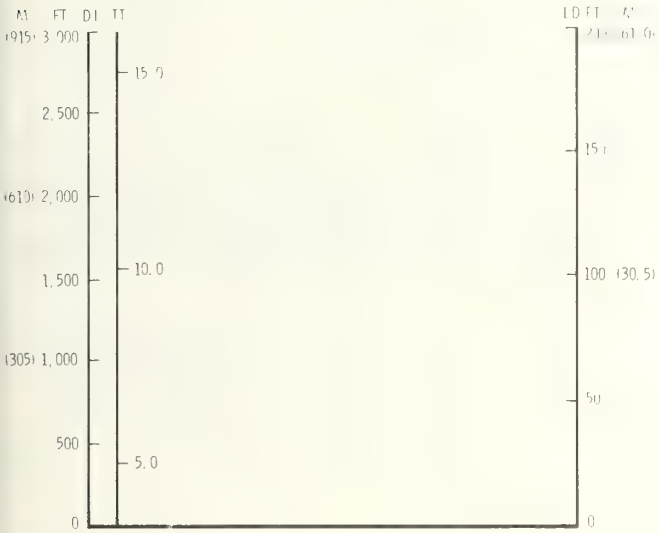

Figure 14.--Performance nomograph, balloon yarding system.

Figure 15.--Helicopter logging with Boeing Vertol 107-11.

Helicopter Yarding

There are more than 35 helicopters (fig. 15) with a 1,000-lb (453-kg) or more payload, and about 12 of these have payloads exceeding 5,000 lb (2 268 kg) that could be used for logging. However, two helicopters with approximately 8,000-lb (3 629-kg) payloads and one with a 20,000-lb (9 072-kg) payload have been used for practically all of the commercial logging to date.

Although expensive to operate, a helicopter has great versatility for logging, and under favorable conditions it is competitive with other systems. In some cases, the helicopter is the only system capable of performing the logging operation; for instance, where roads are prohibited and yarding distances are too great for balloon or cable logging.

The following data are averages for three helicopters:

Helicopter	No. turns	TT *Minutes*	NL	VOL *Bd.ft.* *(m^3)*	DI *Feet* *(m)*
Boeing Vertol 107-11	777	2.4	1.9	499.5 (2.26)	1,184 (360)
Sikorsky S-61	309	2.9	2.2	450.6 (2.04)	2,546 (774)
Sikorsky S-64	86	3.0	3.2	3,101.4 (14.03)	1,232 (375)

Tree Processors

Machines that combine harvesting operations, or perform operations in the field that are normally done elsewhere, are becoming increasingly common. Not many of these machines are in common use in the Northern Rocky Mountain area; however, single-stem feller-bunchers have become more popular the past 10 years.

Feller-Buncher

Many machines now available perform the felling-bunching (fig. 16) operation. As the name implies, they fell the tree (usually by shearing) and place it in a pile designed to facilitate skidding. Most models are capable of handling trees up to 24-26 inches (0.61-0.66 m) in diameter, and can operate effectively on slopes up to about 15 percent. They are mounted on either a rubber-tired or tracked tractor. Track mounting is most popular because it is more stable and because great speed is often unimportant. In recent years, feller heads have been combined with accumulators to improve production for thinning dense stands of small timber. Table 9 gives production figures from Coughran[1] for single-stem and accumulating feller-buncher heads mounted on loaders or excavators, and for a tree combine. Accumulators are much more efficient for the smaller stems that would typically be encountered in thinning operations.

[1]Coughran, Sam. [n.d.] Feller-buncher application. Unpubl. rep. Rome Industries, Cedartown, Ga.

Figure 16.--Feller-buncher harvesting lodgepole pine.

Figure 17.--Feller-buncher-limber designed to clearcut small, dense timber stands.

Feller-Buncher-Limber

This type of processor has been available for several years and has been used primarily for pulpwood operations (fig. 17). It is most effective in the smaller, dense stands on relatively flat terrain for clearcutting operations.

Mobile Chipper

Chipping in the woods (fig. 18), usually at the landing, although a relatively old concept, has not been used much anywhere until the past several years. It is not now in use in the Northern Rocky Mountain area because the few pulp mills in the area are adequately supplied by sawmill residue.

In a whole-tree experimental lodgepole pine loggin[g] study in Wyoming (Gardner and Hartsog 1973) piece siz[e] averaged 13.6 logs/M bd. ft. (61.5 logs/m^3) and productio[n] averaged 57.0 tons/h (52.0 t/h) (productive hours) for th[e] Morbark Chipharvestor SL-22 shown in figure 18.

Log Loaders

Various kinds of loaders, from A-frames to hydrauli[c] knuckle-boom loaders, are being used. The loade[r] selected for a harvesting operation depends on th[e] timber size and method of logging. More types and make[s] of equipment are available for loading than for any othe[r]

Table 9.--Production in trees per hour for feller-bunchers (FB) and tree combines (TC)

D.B.H.	85 hp grapple feller	100 hp loader, single stem FB	130 hp excavator, single stem FB	100 hp loader, accumulator FB	130 hp excavator, accumulator FB	70 hp loader TC
Inches						
3						350
4				270	240	320
5				250	220	280
6		125	150	200	200	260
7		120	145	160	165	210
8		120	140	140	150	160
9		115	135	120	140	140
10	90	110	130	110	135	130
12	88	105	130	105	130	90
14	88	105	120	100	120	
16	85	100	120	100	120	
18	85	95	110	95	110	

logging operation. The most versatile loader is the hydraulic knuckle-boom because it gives such positive control of the log.

Figure 18.--Mobile chipper processing lodgepole pine residue.

Heel-Boom Loader

Heel-boom loaders (fig. 19) are equipped with either a grapple or tongs. The grapple is the more versatile because it can be operated by the operator in the cab of the loader. The logs are heeled against a jam for control.

Figure 19.--Heel-boom loader.

Knuckle-Boom Loader

The knuckle-boom loader (fig. 20) gives positive control of the log as it rests against a jam, and the log can be placed very accurately wherever desired on a truck.

Figure 20.--Hydraulic knuckle-boom loader.

Long-Boom Loader

Long booms (fig. 21) are usually used when logs must be loaded from decks that are difficult to reach, such as those at or near the bottom of a road fill. This type of loading usually requires a tong and tong setter.

Figure 21.--Long-boom loader.

Front-End Loader

Front-end loaders are either tracked (fig. 22) or rubber-tired (fig. 23) and load from the front as shown.

Figure 22.--Track-mounted front-end loader.

Figure 23.--Rubber-tired front-end loader.

The following production data are averages for the loading equipment listed:

Equipment type	No. turns	TT *Minutes*	NL	VOL *Bd.ft. (m^3)*	W *Lb (kg)*
Heel-boom/ grapple	635	0.6	1.2	194.8 (0.88)	1,415 (642)
Long-boom/ tongs	277	.5	1.2	183.7 (0.83)	1,390 (630)
Long-boom/ air tongs	99	.7	1.1	54.7 (0.25)	516 (234)
Jammer	192	1.6	1.0	220.7 (1.00)	1,876 (851)

This summarizes the general equipment types used fo[r] various logging systems in the Northern Rocky Mountai[n] area. Most of this same equipment or same type of equipment is used to varying degrees in other areas of the Unite[d] States and abroad.

LOGGING COSTS, FUEL REQUIREMENTS, AND SYSTEM DESIGN

Logging costs and energy consumption vary wit[h] efficiency and, therefore, depend on the equipment an[d] manpower applied to a harvesting situation. The fundamentals of planning are the same as for any other process however, the planning of logging has generally lagge[d] behind most other industries because of lack of vit[al] information, difficult environmental conditions, lack o[f] trained logging engineers, or just lack of interest. Becaus[e] of the high cost of modern logging equipment, especiall[y] for equipment such as helicopters, planning has increase[d] in the past few years.

In nearly all of the Experiment Station's studies time an[d] motion were measured using a stopwatch, so productivit[y] could be measured, predicted, and converted to cost. Th[e] following sections describe and illustrate a method f[or] estimating production costs and designing loggin[g] systems.

Estimating Costs and Fuel Consumption

Costs can be estimated from the production data in th[e] previous sections by using equipment and manpower cos[ts] appropriate for the place and time. The Internal Reven[ue] Service accepts several methods of depreciating equipment; the operation should use the one that best fits t[he] situation. We have used straightline depreciation and [a] standard method of computing fixed and operating cos[ts] for equipment. The form used is shown in the appendi[x]. Wage rates common to the area are used.

Energy consumption estimates, based on average fu[el] consumption of equipment types applied to producti[ve] hours, can be used to compare the relative ener[gy] efficiency of various systems on a unit basis: cubic fo[ot], board foot, cubic meter.

To estimate costs and energy consumption, the plann[er] needs the usual information about variables such [as] average piece size, number of chokers, number of lo[gs] per cycle, average yarding distance, and so on. In t[he] following examples turn times will be computed using t[he] appropriate equation. (Use of nomographs, or tables f[or] skidders and yarders, was discussed in a previous section of this report.)

Example No. 1

given: - running skyline system logging uphill in a shelterwood cut
- average skidding distance - 500 ft (152 m)
- average piece size - 13 ft^3 (0.37 m^3)
- average lateral skidding distance = 50 ft (15.2 m)
- average weight of load/turn - 3,000 lb (1 361 kg)
- average logs per turn = 4.5
- average productivity* = 0.67

from page 15, use equation 1, or use table 2 on page 8.

Volume per hour

**LN (Turn Time) = 1.458 + (0.001) (0.48654) DI + 0.0011 LD + (0.001) (0.00896) W
= 1.458 + 0.24 + 0.06 + 0.02
= 1.78

TT = *5.93 min*

Volume/turn = 13.0 ft^3 (0.368 m^3) (average piece size) x 4.5 (average number of logs)
= *58.5 ft^3*

Productivity = *58.5 ft^3 (1.65 m^3)/turn* ÷ 5.93 min/turn
= 9.87 ft^3 (0.279 m^3)/min or *592 ft^3 (16.8 m^3)/h*

Running skyline equipment and crew cost

- equipment Skagit GT-3 (fixed and operating cost)	=	$42.00/h
- crew: operator	=	7.20
chaser	=	6.60
2 choker setters @ 6.60	=	13.20
1/2 foreman charge @ 7.20 (assume two sides operating)	=	3.80
1 rigger (half of crew) @ 6.60	=	6.60
Total	=	$79.40/h

Unit cost = *$79.40/h* ÷ 592 ft^3 (16.8 m^3)/h ÷ 0.67 (ave. prod.)
= *$0.200/ft^3$*
or = *$0.032/bd.ft.*
or = *$32.00/M bd.ft. ($7.06/m^3)*

*Percentage of time actually spent yarding.

**LN = natural log.

Example No. 2

given: - 120 BHP rubber-tired skidder
- average total skidding distance = 1,000 ft (304 m)
- average piece size = 12.0 ft^3 (0.34 m^3)
- average logs per cycle = 7.0
- average volume = 520 bd.ft. (2.35 m^3)
- average productivity = 0.70

from page 3, use equation for 120 BHP, or use figure 6b on page 5.

Volume per hour

TT = -0.1971 + 1.1287 NL + 0.0045 VOL + 0.0063 DITOT
= -0.1971 + 7.90 + 2.34 + 6.30

TT = 16.34 min

Volume/turn = 12.0 ft^3 (0.34 m^3) (average piece size) x 7.0 (average number of logs)
= *84.0 ft^3* (2.38 m^3)

Productivity = *84.0 ft^3* (2.38 m^3)/turn ÷ 16.34 min/turn
= 5.14 ft^3 (0.146 m^3)/min
or *308 ft^3* (8.73 m^3)/h

Skidder and operator cost

- skidder	=	$9.40
- operator	=	$6.60
Total		$16.00/h

Unit cost = $16.00/h ÷ 308 ft^3 (8.73 m^3)/h ÷ 0.70 (ave. prod.)
= *$0.0742/ft^3$*
or = *$0.01187/bd.ft.*
or = *$11.87/M bd.ft.* ($2.62/m^3)

Example No. 3

given: - heel-boom/grapple loader
- average piece size = 11.0 ft^3 (0.31 m^3)
- average productivity = 0.60

from page 20, use averages for heel-boom.

Volume per hour

Average TT = *0.6 min*

Average NL = 1.2

Volume/turn = 11.0 ft^3 (0.31 m^3) (average piece size) × 1.2 (average number of logs)
= 13.2 ft^3 (0.373 m^3)

Productivity = 13.2 ft^3 (0.373 m^3)/turn ÷ 0.6 min/turn
= 22.0 ft^3 (0.63 m^3)/min
or 1,320 ft^3 (37.4 m^3)/h

Loader and operator cost

- loader	=	$15.50
- operator	=	7.20
Total		$22.70/h

Unit cost = *$22.70/h* ÷ 1,320 ft^3 (37.4 m^3)/h ÷ 0.60 (ave. prod.)
= $0.0287/$ft^3$
or = *$0.00459/bd.ft.*
or = *$4.59/M bd.ft.* ($1.01/m^3)

Simulating Logging System Design

Computer programs are available, some of which are listed in the references, for simulating logging systems. Such programs can be used when a planner has access to a computer and the necessary input for analysis. When a computer is not available, other means can be used to help design a system. Gardner's method (1966) is expanded to include energy requirements and is used to illustrate how the foregoing information might be used.

The example shows a trial and error approach to balancing the equipment for a system to harvest a hypothetical timber stand averaging 11-13 ft^3 (0.31-0.37 m^3) piece size by clearcutting in an area with slopes of 15 percent or less. (If a computer is available, this step should probably be used anyway to estimate equipment

requirements for input for the first trial run.) The example assumes a hot logging operation--all equipment operating simultaneously. The felling-bunching and skidding operations could have been separated from loading and hauling; for example, if adequate decking space was available and it was desired to load and haul part or all of the harvested material later.

For this example we have used the production estimated for the conditions of previous examples No. 2 and 3 for skidding and loading. The estimated production for the feller-buncher and the hauling were taken from other studies listed in the references. (A 40-mile haul is assumed for the hauling production.)

Any system, of course, can only produce at the rate of the least productive unit or combination of units. For trials 1 and 2, the loader controls the rate, and for trial 3, the skidders control. The objective is to balance production in column (6) as well as possible by adjusting the number of units in column (5).

For fuel consumption computed in columns (9), (10) and (11), average consumption figures for diesel-powere units provide for comparisons of systems. For tracke vehicles fuel consumption is 0.04 gal/hph; for wheele units, 0.025 gal/hph. Fuel consumption can var considerably, depending on the condition of the equip ment, the operator, altitude, season of the year, and s on. If a logging system planner has better informatio about fuel consumption, it should be used. (Note on trial that fuel costs are approximately 12 percent of th estimated harvest cost. This figure is very likely to increas in the years ahead.)

Trial 2 produced a better balance of equipment use an therefore lower cost and energy consumption. Thi relatively simple procedure, largely dependent on goo production estimates, represents the minimum analysi that should be done before assigning equipment to an logging operation.

Trial 1.--Logging system design--cost and fuel consumption estimates

Operation (1)	Equipment: Description (2)	Equipment: Cost per hour (3)	Estimated production per hour (4)	Estimated number of units (5)	Production (6)	Cost: Per hour (7)	Cost: Per M ft³ (8)	Horse-power (9)	Fuel consumption (10)	Fuel consumption (11)
			Ft³		Ft³/h(m³/h)				Gal/h	Gal/M ft³ (Gal/m³)
Felling/ bunching	Feller/ buncher	$25.00	1,500	1	1,500 (42.4)	$ 25.00	$18.94	130	5.20	3.94 (0.14)
Skidding	RTS	16.00	310	5	1,550 (43.9)	80.00	60.61	130	16.25	12.31 (0.43)
Loading	Heel B/ grapple	23.00	1,320	1	1,320 (37.4)	23.00	17.42	130	5.20	3.94 (0.14)
Hauling	Tk/Trlr (6.0 M bd.ft.)	20.00	300	5	1,500 (42.4)	100.00	75.76	220	27.50	20.83 (0.74)
					Totals	$228.00	$172.73		54.15	41.02 (1.45)

Cost per M bd.ft. and m³: $\frac{\$172.73 \text{ M ft}^3}{6.25}$ = $27.64 M bd.ft. ($6.10/m³)

Estimated fuel cost: 41.02 gal x $0.50/gal = $20.51/$172.73 - 12 percent of total

Trial 2.--Logging system design--cost and fuel consumption estimates

Operation (1)	Equipment: Description (2)	Equipment: Cost per hour (3)	Estimated production per hour (4)	Estimated number of units (5)	Production (6)	Cost: Per hour (7)	Cost: Per M ft³ (8)	Horse-power (9)	Fuel consumption (10)	Fuel consumption (11)
			Ft³		*Ft³/h(m³/h)*				*Gal/h*	*Gal/M ft³ (Gal/m³)*
Felling/ bunching	Feller/ buncher	$25.00	1,500	2	3,000 (84.9)	$ 50.00	$18.94	130	10.40	3.94 (0.14)
Skidding	RTS	$16.00	310	9	2,790 (79.0)	144.00	54.54	130	29.25	11.10 (0.39)
Loading	Heel B/ grapple	23.00	1,320	2	2,640 (74.7)	46.00	17.42	130	10.40	3.94 (0.14)
Hauling	Tk/Trlr	20.00	300	9	2,700 (76.4)	180.00	68.18	220	49.50	18.75 (0.66)
					Totals	$420.00	$159.09		99.55	37.71 (1.33)

Cost per M bd.ft. and m³: $\frac{\$159.09}{6.25}$ = $25.45/M bd.ft. ($5.62/m³)

Trial 3.--Logging system design--cost and fuel consumption estimates

Operation (1)	Equipment: Description (2)	Equipment: Cost per hour (3)	Estimated production per hour (4)	Estimated number of units (5)	Production (6)	Cost: Per hour (7)	Cost: Per M ft³ (8)	Horse-power (9)	Fuel consumption (10)	Fuel consumption (11)
			Ft³		*Ft³/h(m³/h)*				*Gal/h*	*Gal/M ft³ (Gal/m³)*
Felling/ bunching	Feller/ buncher	$25.00	1,500	3	4,500 (127)	$ 75.00	$17.28	130	15.60	3.59 (0.13)
Skidding	RTS	16.00	310	14	4,340 (123)	224.00	51.61	130	45.50	10.48 (0.37)
Loading	Heel B/ grapple	23.00	1,320	4	5,280 (149)	92.00	21.20	130	20.80	4.79 (0.17)
Hauling	Tk/Trlr	20.00	300	15	4,500 (123)	300.00	69.12	220	82.50	19.00 (0.67)
					Totals	$691.00	$159.16		164.40	37.88 (1.34)

Cost per M bd.ft. and m³: $\frac{\$159.22}{6.25}$ = $25.48/M bd.ft. ($5.62/m³)

SUMMARY

Most of the equipment and methods used for logging in the Northern Rocky Mountain areas have been discussed. Production rates and methods for estimating production, fuel requirements, and costs are presented. Using the information presented in this report, one can plan a logging system for most situations found in the Northern Rocky Mountain area and estimate probable logging costs and fuel requirements. Logging systems should always be carefully evaluated in the office before using them on the ground. If the information presented here is used as suggested, a logging job can be reasonably well planned.

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APPENDIX

Data Collection and Analysis

Data collection was performed by time study crews at logging operations throughout the Northern Rocky Mountain area and for some operations, such as helicopters, at locations in the Pacific Northwest. Each element such as travel empty, setting chokers, etc., is usually timed by continuous stop-watch readings. Variables affecting production such as terrain, log size, skidding distance, and others are also recorded. The techniques used for data collection are described in detail in a publication by Gibson and Rodenberg (1975).

The analysis of logging systems presents many problems, discussed in the introduction. However, information from these studies is the most effective means of improving logging efficiency and cost when it is used as a tool for planning. Production equations are the final result of most logging studies.

From past studies, variables influencing logging production have been well defined and usually include a combination of some of the following:

- -distance, skidding, or yarding (lateral distance when it applies)
- -log volume or weight
- -number of logs
- -timber stand density
- -slope
- -human factors
- -deck location and size
- -landings
- -foreign element delays
- -terrain
- -weather.

All of the above variables are self-explanatory, except foreign elements and human factors. Foreign elements are delays associated with machines, manpower, material, or environmental factors. Human factors, for example, have usually been evaluated by rating the operators. The principal factors influencing production for each equipment type are shown in the regression equations in this publication. Most of the equations include distance, and either volume or weight, and number of logs. These variables were usually the most significant. Many of the other variables were found to be either insignificant or constitute only minor contributions to the correlation coefficient and were therefore not included in the final equations.

The format and procedure used to develop equipment cost estimates is indicated by the following data form.

EQUIPMENT DATA SHEET

Specifications

Mfg. ____________________

Model ____________________

Engine ____________________

General Specs. ____________________

Standard Costs

Est. Life (N) ____________________

Est. Use/Yr. ____________________

Purchase Cost & Fgt. (I) ____________________

Sal. Value (S) ____________________

Fixed	**Ann.**
Dep. $\frac{I-S}{N}$	____________
Ave. Value of Invest. $\frac{I-S(N+1)}{2N}$ = ____________	
10% AVI for Int., Tx. and Storage	____________
Repairs and Maintenance (100% of Dep.)	____________
Total Ann. Cost	____________
Oper.	**Hour**
Fixed Costs ÷ Hours of Use	____________
Fuel, Lub., etc.	____________
Total Cost/h	____________

The Intermountain Station, headquarted in Ogden, Utah, is one of eight regional experiment stations charged with providing scientific knowledge to help resource managers meet human needs and protect forest and range ecosystems.

The Intermountain Station includes the States of Montana, Idaho, Utah, Nevada, and western Wyoming. About 231 million acres, or 85 percent, of the land area in the Station territory are classified as forest and rangeland. These lands include grasslands, deserts, shrublands, alpine areas, and well-stocked forests. They supply fiber for forest industries; minerals for energy and industrial development; and water for domestic and industrial consumption. They also provide recreation opportunities for millions of visitors each year.

Field programs and research work units of the Station are maintained in:

Boise, Idaho

Bozeman, Montana (in cooperation with Montana State University)

Logan, Utah (in cooperation with Utah State University)

Missoula, Montana (in cooperation with the University of Montana)

Moscow, Idaho (in cooperation with the University of Idaho)

Provo, Utah (in cooperation with Brigham Young University)

Reno, Nevada (in cooperation with the University of Nevada)

United States
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Forest Service

**Intermountain
Forest and Range
Experiment Station**

General Technical
Report INT-119

September 1981

An Annotated Bibliography of Wind Velocity Literature Relating to Forest Fire Behavior Studies

RESEARCH SUMMARY

This bibliography was developed primarily for fire behavior research; however, the information should also be useful in support of other forest protection studies. Most of the references deal with surface wind velocities acting within the local scale of most forest fires. Subjects not covered include instrumentation, installation, observational techniques, forecasting, and fire-induced winds such as fire whirls and indraft flow. All foreign references given are either in English or have English translations. Some references were obtained through a WESTFORNET literature search. With one exception, the period covered is from 1940 through 1979.

THE AUTHOR

ROBERT G. BAUGHMAN holds B.S. and M.S. degrees in meteorology and climatology from the University of Washington, Seattle. From 1954 to 1958 he was engaged in arctic research with the U.S. Army Corps of Engineers. Since joining the Forest Service in 1958, he has held the position of research meteorologist at the Northern Forest Fire Laboratory and has been involved in research on thunderstorms, lightning, weather modifications, and forest meteorology.

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**Intermountain
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General Technical
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An Annotated Bibliography of Wind Velocity Literature Relating to Forest Fire Behavior Studies

**Compiled by
Robert G. Baughman**

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1. Albini, F. A., and R. G. Baughman.
1979. Estimating windspeeds for predicting wildland fire behavior. USDA For. Serv. Res. Pap. INT-221, 12 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.

A means of estimating the ratio of the mean windspeed acting at flame height to the windspeed at 20 feet above the vegetation cover is given. A model for relating windspeed within a uniform forest canopy to the windspeed above the canopy is presented. Important variables in the model include stand height, crown closure, foliar surface-to-volume ratio, and crown bulk density.

2. Alexander, A. J., and C. F. Coles.
1971. A theoretical study of wind flow over hills. *In* Proc. 3rd Int. Congr. on Wind Loads on Buildings and Structures, Vol. 1, paper 10. p. 95-103.

The equations of motion are solved numerically to compute the flow over a hill of arbitrary shape. Examples are presented for two hill profiles and two initial velocity profiles. Results indicate the hill influence does not extend beyond four times its height and that a very rapid increase in velocity to a maximum value occurs at the brow of the hill.

3. Alexander, Robert R.
1964. Minimizing windfall around clear cuttings in spruce-fir forests. For. Sci. 10 (2):130-142.

A study of windfalls in clearcut areas identified situations and conditions where windthrow hazards were above and below average. Guidelines to minimize windfall are given.

4. Allen, L. H., Jr.
1968. Turbulence and wind speed spectra within a Japanese larch plantation. J. Appl. Meteorol. 7(1):73-78.

A log-profile analysis yielded a wide range of values for the roughness length and the zero-plane displacement height. Large eddies penetrated deeper in the forest after needle fall and during high winds. Most of the variation in windspeed was associated with gusts of about 100-meter wave length. Power spectra showed considerable modification due to tree spacing in the most dense portion of the canopy.

5. Anderson, Gerald E.
1971. Mesoscale influence on wind fields. J. Appl. Meteorol. 10(3):377-386.

Simple analyses based on the divergence equation permit calculation of wind fields that appear more realistic than wind fields produced by other objective analyses. The analyses, which are computationally simple, provide an objective procedure for real-time, forecast, or hypothetical cases.

6. Arya, S. P. S., and M. S. Shipman.
1979. A model study of boundary layer flow and diffusion over a ridge. Fourth Symp. on Turbulence, Diffusion, and Air Pollution, Meteorol. Soc. [Reno, Nev., Jan. 15-18, 1979]. p. 584-591.

The flow of air over a low ridge was investigated by means of experiments conducted in a large wind tunnel. Results indicate the flow decelerates slightly upwind of the ridge and accelerates as it passes over the ridge with a maximum just above the ridgetop. The maximum velocity deficit in the wake occurs somewhere between one and two ridge heights downstream of the ridge.

7. Ayer, Harold S.
1960. The wind profile at the crest of a large ridge. Mon. Weather Rev. 88(1):19-23.

Observations were obtained of wind movement at four levels in a layer 2-14 m above the crest of a ridge. The data are classified by prevailing wind types. It appears that the observed turbulent wind profile is not fully developed at the ridge crest.

8. Bache, D. H., and M. H. Unsworth.
1977. Some aerodynamic features of a cotton canopy. Q. J. Royal Meteorol. Soc. 103 (435): 121-134.

Analysis of profiles measured over irrigated cotton showed the crop boundary layer remained stable throughout most of the day. Wind profiles suggested that moment-

um was absorbed mostly in the upper layers of the canopy. An analysis showed that the aerodynamic features of the upper layers of the canopy were characterized by friction velocity and height of the zero-plane displacement.

9. Baines, G. B. K.
1972. Turbulence in a wheat crop. Agric. Meteorol. 10(1/2):93-105.

Wind velocity measurements were made at several heights (from 8 to 94 cm) within the crop stand. Plant-generated turbulence and the dissipation of kinetic energy were studied. The Strouhal number was used to predict the scale of turbulence generated by leaves and stems.

10. Ball, Joseph A.
1975. Concept for a high-resolution toposcale wind model to estimate surface wind in a complex terrain. 12 p. Mission Res. Corp., Santa Barbara, Calif.

Concepts are given for a numerical model to estimate winds in mountainous terrain. Required are topographic data and observations or predictions of surface temperature and wind at several locations or an estimated general surface wind and temperature from a sounding near the modeled area.

11. Barad, Morton L.
1961. Low-altitude jet streams. Sci. Am. 205(2): 120-131.

A popular discussion of the general mechanics of the low-level jetstream that often produces strong winds at night between 800 and 2,000 feet above the ground. The winds appear to play a role in the birth of storms.

12. Barad, Morton L.
1963. Examination of a wind profile proposed by Swinbank. J. Appl. Meteorol. 2(6):747-754.

A theoretical model of windspeed profiles in the lower boundary layer during conditions of nonneutral temperature stratification was examined. The Swinbank derivation depends upon an assumption that the Monin-Obukhov length is constant. Analyses of observations show this is not so. It is concluded that the Swinbank hypothesis is not verified by data.

13. Barr, Sumner.
1971. A modeling study of several aspects of canopy flow. Mon. Weather Rev. 99(6):485-493.

The problem of steady flow in a horizontally infinite canopy under neutral thermal stratification is treated theoretically. The resulting model is then used as a boundary condition for a nonlinear numerical model designed to study transition regions near the leading and trailing edges of a canopy. The model shows a wave effect downstream from a leading edge and a tendency for splitting of the flow near a windward edge.

14. Barrows, J. S.
1951. Fire behavior in the Northern Rocky Mountain Forests. USDA For. Serv. Stn. Pap. No. 29, 103 p. North. Rocky Mt. For. and Range Exp. Stn., Missoula, Mont.

A well illustrated and descriptive discussion of fire behavior including the effect of weather elements is presented. Wind velocity is discussed on pages 29-33. The Northern Rocky Mountain scale of wind velocity for use in estimating wind velocities is shown.

15. Baynton, Harold W., W. Gale Biggs, Harry L. Hamilton, Jr., Paul E. Sherr, and James J. B. Worth.
1965. Wind structure in and above a tropical forest. J. Appl. Meteorol. 4(6):670-675.

Winds were measured, up to a height of 200 feet, in and above a tropical rain forest in northern Columbia. Windspeeds below the canopy were only 1 to 5 percent of that measured 50 feet above the canopy. Wind directions below the canopy appear to be disorganized.

16. Bergen, James D.
1969. Cold air drainage on a forested mountain slope. J. Appl. Meteorol. 8(6):884-895.

An attempt was made to relate the volume and velocity of flow to the net radiation balance on a forested slope. The local mean windspeed varies as the square root of the temperature drop down the slope and the sine of the angle of the slope. The potential temperature drop down the hillside varies approximately as the two-thirds power of the estimated net radiation loss.

17. Bergen, James D.
1971. Vertical profiles of windspeed in a pine stand. For. Sci. 17(3):314-321.

Simultaneous measurements of windspeed were made at six heights extending to the top of a lodgepole pine stand. The windspeed profile expressed as a fraction of the friction velocity above the stand is invariant for a wide range of windspeeds above the canopy. The profiles show a minimum in the live crown and a subcanopy maximum.

18. Bergen, James D.
1974. The independence of the point-to-point variations in windspeed and temperature in a lodgepole pine stand. USDA For. Serv. Res. Note RM-258, 2 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

The correlations between local variations in air temperature and windspeed were examined. The results indicate that the point-to-point deviations are independent. The independence of wind and temperature fields supports the use of averages of temperature and windspeed when applying energy balance techniques at the forest floor.

19. Bergen, James. D.
1974. Variation of windspeed with canopy cover within a lodgepole pine stand. USDA For. Serv. Res. Note RM-252, 4 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

A linear correlation suggests independence between point-to-point variations in speed at any level and variation at canopy cover.

20. Bergen, James D.
1975. Air movement in a forest clearing as indicated by smoke drift. Agric. Meteorol. 15(2):165-179.

Cinematic observations were made of smoke drift in a clearing (10 by 50 cm) cut in an even-aged stand (average height 10 m) of lodgepole pine. Results indicate a continuous alteration between separated (rotor) and unseparated (through-flow) flow in fair agreement with the eddy shedding frequency of a flat plat in uniform flow. The vortex rotor appears to dominate the distribution and direction of the maximum windspeeds in the clearing.

21. Bergen, James D.
1975. An approximate analysis of the momentum balance for the airflow in a pine stand. *In* Heat and mass transfer in the biosphere, part 1. Transfer processes in the plant environment. p. 287-298. D. A. deVries and N. H. Afgan, eds. Scripta Book Co., Washington, D.C.

Estimates of velocity profiles, volume drag coefficient, and effective viscosity were obtained from windspeed and foliage distribution measurements. Results suggest that live branches are the characteristic drag element and that the effective viscosity has an appreciable dispersive component.

22. Bergen, James D.
1975. Windspeed distribution in an isolated forest clearing. Twelfth Agric. and For. Meteorol. Conf. [Tucson, Ariz., Apr. 14-16, 1975]. p. 45-46. Am. Meteorol. Soc.

Measurements made in an extended 28 by 49 meters clearing are compared to those made earlier in a 10 by 49 meters clearing. Higher windspeeds were measured in the larger clearing.

23. Bergen, James D.
1976. Air flow in forest canopies--a review of recent research in modeling the momentum balance. 47 p. Paper presented at the Fourth Natl. Conf. on Fire and Forest Meteorol. [St. Louis, Mo., Nov. 16-18]. [Abstract published in Proceedings.]

Presents an overview of the state-of-the-art in mathematical modeling of airflow in forest canopies. Three recent models are examined as divergent solutions to the modeling problem. None of the models correctly predicts the velocity maximum found in the subcanopy space in field and wind tunnel investigations. Apparently, there is currently no generally accepted model for the momentum balance of airflow in a forest canopy.

24. Bergen, James D.
1976. Some measurements of the adiabatic wind profile over a tall and irregular forest. Fourth Natl. Conf. on Fire and Forest Meteorol. [St. Louis, Mo., Nov. 16-18, 1976]. p. 116-121. USDA For. Serv. Gen. Tech. Rep. RM-32. Rocky Mt. For. and Range Exp. Stn., Fort Collins. Colo.

Results indicate: (1) an increase of roughness length with windspeed and (2) a general decrease in displacement thickness with speed.

25. Bergen, James D.
1976. Windspeed distribution in and near an isolated narrow forest clearing. Agric. Meteorol. 17(2): 111-133.

Windspeeds were measured on a three-dimension array in a 10 by 50 m clearing cut in a 10-m high lodgepole pine stand. The ratio of local windspeed to above canopy friction velocity is independent of the latter and stability. The flow shows extensive separation in the time average. The effect of the clearing extends more than five tree heights behind the clearing but is negligible upwind of the clearing. Minimum speeds occurred at the clearing center while maximum speeds occurred at subcanopy levels and above the tree edge of the clearing.

26. Bergen, James D.
1979. The windflow to the lee of a forest edge. Fourteenth Conf. on Agric. and For. Meteorol. [Minneapolis, Minn., Apr. 2-6, 1979]. p. 170-172.

A first-order model of airflow in forest clearings is presented. The model predicts some of the general features of observed airflow in a clearing; it should be useful in predicting air and soil temperature and snow diposition in clearings.

27. Berglund, Erwin R., and Richard J. Barney.
1977. Air temperature and wind profiles in an Alaskan lowland black spruce stand. USDA For. Serv. Res. Note PNW-305, 12 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Results indicate windspeeds measured 4.5 meters above an Alaskan black spruce stand are four times faster than those measured 0.5 meters above ground vegetation.

28. Berman, E. A., D. E. Steffen, G. Taylor, and D. Kringel.
1977. Numerical simulation of flow fields in rough terrain. *In* Joint Conf. on Applications of Air Pollution Meteorology. [Sponsored by the Am. Meteorol. Soc. and the Air Pollution Control Assoc., Salt Lake City, Utah, Nov. 29 to Dec. 2, 1977.] p. 204-208.

The theoretical basis and computational formalism of a wind model is presented. The model (WINDS) generates a nondivergent wind field during stable or neutral atmospheric conditions. The results of a case study in the Los Angeles area are given.

29. Berman, S.
1965. Estimating the longitudinal wind spectrum near the ground. Q. J. Royal Meteorol. Soc. 91(389):302-317.

Presents a graphical procedure for estimating the spectrum of the longitudinal wind component from height, mean windspeed, roughness length, and stability data. Observations suggest the spectrum is more variable in the lower frequency as compared with the higher frequencies. No systematic variation with height could be seen.

30. Bhumralkar, Chandrakant M.
1973. An observational and theoretical study of atmospheric flow over a heated island: Part 1. Mon. Weather Rev. 101(10):719-730.

Part 1 is the observational part of a two-part report. Observations show that evaporational cooling of the environment has an important influence on the behavior perturbations induced by the heated island.

31. Bhumralkar, Chandrakant M.
1973. An observational and theoretical study of atmospheric flow over a heated island: Part 2. Mon. Weather Rev. 101(10):731-745.

In part 2, a general theoretical nonlinear model is presented that can simulate the reaction of the atmosphere to surface heating and friction. The model includes continuity equations that predict water vapor, cloud water, and liquid water. Results show that the larger the temperature excess of the heat source, the greater the intensity of the induced disturbance.

32. Blackadar, Alfred K.

1957. Boundary layer wind maxima and their significance for the growth of nocturnal inversions. Bull. Am. Meteorol. Soc. 38(5):283-290.

A sharp windspeed maximum frequently observed at night below 3,000 feet is explored in terms of a low-level jet. The wind maxima, usually at the top of the nocturnal temperature inversion, is supergeostrophic and associated with large values of wind shear at low levels. The supergeostrophic windspeeds suggest that inertia oscillation is induced when the constraint imposed by daytime mixing is released by the initiation of an inversion at about the time of sunset.

33. Blackadar, Alfred K.

1960. A survey of wind characteristics below 1500 feet. *In* Topics in engineering meteorology. Meteorol. Monogr. 4(22):3-11.

The survey includes work by Prandtl, Deacon, Monin, and Obukhov, and Ellison. Adiabatic and diabatic wind profiles are discussed. The vertical distribution of peak velocities is also discussed. A brief theory of the low-level jet wind is given.

34. Blackadar, Alfred K.

1976. Modeling the nocturnal boundary layer. Third Symp. on Atomospheric Turbulence, Diffusion, and Air Quality. [Sponsored by the Am. Meteorol. Soc., Oct. 19-22, 1976, Raleigh, N.C.] p. 46-49.

The model presented was designed to provide the time height distribution of temperature and wind during the course of the night given the geostrophic wind and the thermodynamic and mechanical properties of the surface.

35. Bonner, William D.

1968. Climatology of the low level jet. Mon. Weather Rev. 96(12):833-850.

Two years of wind data from 47 radiosonde stations in the United States are used to determine the graphical and diurnal variations in the frequency of strong low level wind maxima. Maximum frequency of occurrence is found in the Great Plains. Diurnal wind oscillations are examined. Oscillation is similar to that described by Blackadar.

36. Bonner, William D., S. Esbensen, and R. Greenberg.

1968. Kinematics of the low-level jet. J. Appl. Meteorol. 7(3):339-347.

Winds and vertical velocities are examined in ten southerly low-level jets. Some jets are strongly supergeostrophic. Air is typically rising downstream from the wind maximum and sinking just upstream from the jet core. This orientation of vertical velocities provides a possible explanation for the high frequency of nocturnal thunderstorms in the Midwest.

37. Bowen, A. J., and D. Lindley.

1974. Measurements of the mean wind flow over various escarpment shapes. Fifth Australasian Conf. on Hydraulics and Fluid Mechanics [Univ. Canterbury, Christchurch, New Zealand, Dec. 9-13, 1974]. p. 212-219.

Wind profiles were obtained to a height of 10 meters above the ground for various positions over a sloping and cliff escarpment. The local windspeed was compared with the undisturbed upstream wind at the same height and expressed as velocity ratios. Values at the velocity ratio varied widely but were commonly within the range of 1.1 to 1.4.

38. Bowen, A. J., and D. Lindley.

1977. A wind-tunnel investigation of the windspeed and turbulence characteristics close to the ground over various escarpment shapes. Boundary-Layer Meteorol. 12:259-271.

Four sharp-edged escarpments with slopes varying between a cliff and a 4:1 gradient were tested. The modifications to the mean wind, turbulence intensity, and energy spectra are described. Results suggest that significant changes in turbulence characteristics occur only in the wake region close behind the crest where a shift o energy to high frequency is evident.

39. Bradley, E. F.

1968. A micrometeorology study of velocity profiles and surface drag in the region modified by a change in surface roughness. Q. J. Roya Meteorol. Soc. 94(401):361-379.

Reports results of experiments where air passes fron one surface to another with different roughness. The variation in surface stress and the development of velocity profiles were observed. A large portion of the surface stress adjustment occurs rapidly after transition. Growth of th modified region follows the 4/5 power law of boundar layer growth.

40. Brier, Glenn W.

1951. The statistical theory of diffusion by turbulen eddies. *In* An atmospheric pollution: a group c contributions. Meteorol. Monogr. 1(4):15-19.

Discusses some of the most important unsolve problems of statistical turbulent theory and the difficultie in applying the theory to diffusion in the atmosphere.

41. Brook, R. R., and K. T. Spillane.

1968. The effect of averaging time and sample dura tion on estimation and measurement of maximum wind gusts. J. Appl. Meteorol. 7(4):567-574.

The ratio of maximum gust drawn from a sample to th ratio of a second maximum gust drawn from a secor sample is derived. A spectral density function is defined s that only one parameter has any effect on the ratio. Su gested practical uses include aviation landing advice f aircraft particularly sensitive to wind gusts.

42. Brook, R. R., and K. T. Spillane.

1970. On the variation of maximum wind gusts wi height. J. Appl. Meteorol. 9(1):72-78.

For stationary strong-wind regimes dominated b "mechanical turbulence," maximum gusts are determin as a function of height and averaging time. The techniq presented should permit those interested to interpret pr sently available extreme-wind gusts data in terms of heig and averaging times appropriate to their problem.

43. Brooks, F. A.

1961. Need for measuring horizontal gradients determining vertical eddy transfers of heat a moisture. J. Meteorol. 18(5):589-596.

Reviews problems and results dealing with irregu shear stress profiles produced by flow over a change surface roughness. Tree interference effects may still evident even at a distance of 50 tree heights.

44. Brown, Arthur A., and Kenneth P. Davis.

1973. Forest fire: control and use. 2d ed. 686 McGraw-Hill Book Co., New York.

The association of wind with fire is discussed in t book. Chapter 7 deals with the effect of wind on fire.

45. Brown, James M.

1972. The effect of overstory removal upon surface wind in a black spruce bog. USDA For. Serv. Res. Note NC-137, 2 p. North Cent. For. Exp. Stn., St. Paul, Minn.

Wind passage was measured over a black spruce canopy at the surface, both under the canopy and in a clearcut strip. Wind below the canopy was 10 percent of that above the canopy; wind in the clearcut strip was 45 percent of the wind above the canopy.

46. Buajitti, K., and A. K. Blackadar.

1957. Theoretical studies of diurnal wind-structure variations in the planetary boundary layer. Q. J. Royal Meteorol. Soc. 83(358):486-500.

The cause of wind variations was sought by finding what periodic variations occur when eddy viscosity is periodic in time and constant with height and when the eddy viscosity is distributed arbitrarily with height. It was concluded that the observed variations can occur only when both the average value of the eddy viscosity and the amplitude of its variations decrease rapidly with height in the lowest third of the friction layer.

47. Buettner, Konrad J. K., and Norman Thyer.

1965. Valley winds in the Mount Rainier area. Archiv. Meteorol., Geophysik and Bioklimatol. Serie B: Alligemeine und biologische klimatologie 14(2):125-147. [In English.]

Airflow within a mountain valley is up the valley during the day and down at night and is compensated by a return flow (antiwind) at a higher level. Speeds reach a maximum in early afternoon and just before sunrise. When a well developed wind system occurred in one valley, well developed systems tended to occur in other valleys in the same area.

48. Bull, G. A. D., and E. R. C. Reynolds.

1968. Wind turbulence generated by vegetation and its implications. *In* Wind effects in the forest. [Suppl. to Forestry, J. Soc. For., Great Britain.] p. 28-37. Oxford Univ. Press.

Wind measurements demonstrate the aerodynamically rough surface of a 26-year-old Scots pine plantation compared with 5-year-old Scots pine and short grass. A hydrostatic channel was used to demonstrate the relative efficiency of a leader of Scots pine to generate turbulence compared with Norway spruce and Douglas-fir leaders.

49. Burnham, J.

1970. Atmospheric gusts - a review of the results of some recent research at the Royal Aircraft Establishment. Mon. Weather Rev. 98(10):723-734.

Wind gusts at lower altitudes, including gusts in and near thunderstorms, were studied. The mathematical modeling of severe gusts relevant to aircraft design is described. Suggestions are made for models that may prove to be more accurate and more physically plausible.

50. Busch, Niels E., John A. Frizzola, and Irving A. Singer.

1968. The micrometeorology of the turbulent flow field in the atmospheric surface boundary layer. Acta Polytech. Scand., Physics including Nucleonics Series 59, 45 p. Copenhagen.

Outlines the background to the Monin-Obukhov similarity theory and extends the theory to the spectra of three-dimensional velocity flow. An analysis of data is presented and compared with other analyses.

51. Businger, J. A., J. C. Wyngaard, Y. Izumi, and E. F. Bradley.

1971. Flux-profile relationships in the atmospheric surface layer. J. Atmos. Sci. 28(2):181-189.

Wind and temperature profiles for a wide range of stability conditions have been analyzed in the context of Monin-Obukhov similarity theory. Direct measurements of heat and momentum fluxes enabled determination of the Obukhov length parameter. A comparison between profile-derived and measured fluxes showed good agreement over the entire stability range of the observations.

52. Byram, George M.

1954. Atmospheric conditions related to blowup fires. USDA For. Serv., Southeast. For. Exp. Stn., Pap. 35, 34 p. Asheville, N.C.

Extreme forest fire behavior is related to low-level jet winds. Various wind profiles that appear to be potential troublemakers are classified by four different types. Lists indicative conditions that give warning of unusual burning conditions.

53. Carl, Douglas M., Terry C. Tarbell, and Hans A. Panofsky.

1973. Profiles of wind and temperature from towers over homogeneous terrain. J. Atmos. Sci. 30(5):788-794.

With small Richardson numbers, no significant deviations from logarithmic profiles were detected up to 150 meters. Under nonneutral conditions, Monin-Obuskhov scaling described the profiles well.

54. Carruthers, Nellie.

1943. Variations in wind velocity near the ground. Q. J. Royal Meteorol. Soc. 69:289-301.

Summarizes the literature relevant to the subject of wind variation near the ground. The article deals with variation in mean wind with height and with gustiness and its relation to change of mean velocity and height. A general approximate law for variation of wind with height is suggested.

55. Cermak, J. E.

1970. Problems of atmospheric shear flows and their laboratory simulation. Boundary-Layer Meteorol. 1(1):40-60.

Presents a good review of air flow problems and an extensive list of references.

56. Chiu, Arthur N. L.

1974-75-78. Wind engineering research digest, vol. 1, 2, 3, Univ. Hawaii, Honolulu. [Available through NTIS, Springfield, Va. 22151.]

A continuing survey of projects in various aspects of wind engineering research.

57. Chrosciewicz, Z.

1975. Correlation between wind speeds at two different heights within a large forest clearing in central Saskatchewan. Infor. Rep. NOR-X-141, 9 p. North. For. Res. Cent., Can. For. Serv., Edmonton, Alta.

Winds were measured at 1.2 meters and 10.0 meters above the ground. A straight-line relationship existed between windspeeds at two different heights. Tables were prepared for estimating midday winds at 10 meters from known winds at 4 meters height.

58. Cionco, Ronald M.

1965. A mathematical model for air flow in a vegetative canopy. J. Appl. Meteorol. 4(4):517-522.

A model was developed that expresses the surface roughness and the density and drag of a vegetative canopy. Computed canopy winds verified that the mixing length is nearly constant with height. Simulated wind profiles were in good agreement with observed data.

59. Cionco, Ronald M.

1972. A wind-profile index for canopy flow. Boundary-Layer Meteorol. 3(2):255-263.

The canopy wind profile is represented by an exponential function containing an index value of the airflow response to the vegetation. The index increases as both density and flexibility increase.

60. Cionco, Ronald M.

1979. A summary of an analysis of canopy index values for different canopy densities. *In* Fourteenth Conf. on Agric. and For. Meteorol. and Fourth Conf. on Bio-Meteorol. sponsored by the Am. Meteorol. Soc. [Minneapolis, Minn., April 2-6, 1979]. p. 107-109.

Windspeed profile data of two different canopy densities have been analyzed and the results indicate their indices of canopy flow behave in a similar manner. The good agreement lends credibility to the future usefulness of the canopy flow index.

61. Cliff, William C.

1977. The effect of generalized wind characteristics on annual power estimates from wind turbine generators. Battelle Memorial Inst., Pac. Northwest Lab., Richland, Wash., PNL-2436, 31 p.

Hourly windspeeds are assumed to have a Rayleigh frequency distribution which requires only a single parameter input (that is, mean value, variance, or higher moment values). A generic set of curves is developed to estimate the average power output of wind turbines.

62. Cliff, W. C., and G. H. Fichtl.

1978. Wind velocity-change (gust rise) criteria for wind turbine design. Battle Memorial Inst., Pac. Northwest Lab., Richland, Wash., PNL-2526, 17 p.

Formulas are developed for estimating the velocity change encountered over the swept area of a wind-turbine rotor system.

63. Cliff, W. C., C. G. Justus, and C. E. Elderkin.

1978. Simulation of the hourly wind speeds for randomly dispersed sites. Battelle Memorial Inst., Pac. Northwest Lab., Richland, Wash., PNL-2523, 21 p.

A technique is presented that simulates hourly windspeeds at any number of dispersed sites within a region. The required input is an hourly windspeed from a representative site and an estimation of size of the region in which the sites will be located.

64. Clodman, J.

1972. Small-scale motions. *In* Meteorological challenges: a history. p. 209-234. D. P. McIntyre, ed. Ottawa, Information, Canada.

Presents a discussion of the importance of mesoscale meteorological process. It is suggested that mesoscale meteorology is an important field of study that has been relatively neglected.

65. Cohen, Edward.

1960. Wind load on towers. *In* Topics of engineering meteorology. Meteorol. Monogr. 4(22):25-42.

A general theory of wind pressure for aerostatic effects and empirical-shape factors for common structural members is presented. Also reports test data on aerodynamic-lift (lateral force) coefficients.

66. Cooper, Robert W.

1965. Wind movement in pine stands. Ga. For. Res. Pap. 33, 3 p. Ga. For. Res. Counc., Macon.

A method is given for converting standard open winds (20 feet above ground) to those expected within different pine forest stands. A wind conversion table is provided for stands ranging from 20 to 70 feet high with basal areas of 20 to 100 square feet per acre.

67. Corby, G. A.

1954. The airflow over mountains. A review of the state of current knowledge. Q. J. Royal Meteorol. Soc. 80(346):491-521.

The review is confined mainly to the work of Quency and Scorer. Some experimental work with models in wind tunnels is considered briefly. A comprehensive field study by researchers who used gliders is summarized.

68. Cormier, Rene' V.

1975. Horizontal variability of vertically integrated boundary layer winds. J. Geophys. Res. 80(24):3407-3409.

The study shows that daytime root mean square windspeed differences are relatively independent of distance. At night, windspeed variability increases with increasing distance.

69. Corotis, Ross B.

1976. Stochastic modeling of site wind characteristics. Energy Res. and Dev. Admin., Div. Solar Energy Final Rep. ERDA/NSF/00357-76/1, 297 p.

Statistical methods and probability models are utilized to determine optimal evaluation procedures for survey data. Persistence of wind is measured in terms of velocity run duration. A general model is developed for the probability of run duration. The observed histograms for velocities exhibit a reasonable fit to both the Chi-square and Weibull distributions.

70. Corotis, Ross B.

1977. Stochastic modeling of site wind characteristics. U.S. Dep. Energy, Div. Solar Energy, Final Rep. RLO/2342-7/2, 143 p.

Statistical analysis procedures and probability models applicable to wind energy conversion sites are developed. Algorithms are used to study variances, fit probability distributions, analyze run duration, and determine correlation structure in the wind. Preliminary results indicate that the probability distributions for both wind velocity and power can be well modeled and calibrated from seasonal mean velocity alone.

71. Corotis, Ross B., Arden B. Sigl, and Michael P. Cohen

1977. Variance analysis of wind characteristics for energy conversion. J. Appl. Meteorol. 16(11):1149-1157.

Autocorrelation and cross-correlation analyses confirm the existence of significant correlation in the wind at a single site for a period of 8 to 12 hours and between sites for similar time lags and separations up to 100 km or more

72. Coulter, J. D.
1967. Mountain climate. *In* Proc. New Zealand Ecol. Soc. 14:40-57.

Climatic data are reported including free air and surface winds.

73. Countryman, Clive M., and DeVer Colson.
1958. Local wind patterns in Wildcat Canyon. USDA For. Serv. Tech. Pap. 28, 12 p. Calif. For. and Range Exp. Stn., Berkeley.

Observations are reported from a network of wind recording instruments. Local conditions frequently exert a major control on local wind patterns. Apparently only strong upper air patterns can extend influence to ground level in the small canyon studied.

74. Countryman, Clive M., M. A. Fosberg, and R. C. Rothermel.
1968. Fire weather and fire behavior in the 1966 Loop Fire. Fire Tech. 4(2):126-141.

The effect of Santa Ana winds on a major fire is described.

75. Cowan, I. R.
1968. Mass, heat, and momentum exchange between stands of plants and their atmospheric environment. Q. J. Royal Meteorol. Soc. 94(402): 523-544.

A model of mass and momentum transfer in the air layer occupied by a stand of plants is presented. An expression for windspeed is given in terms of the drag of the vegetation. Computed windspeed profiles are shown.

76. Cramer, H. E.
1960. Use of power spectra and scales of turbulence in estimating wind loads. *In* Topics in engineering meteorology. Meteorol. Monogr. 4(22):12-18.

Measurements of turbulent wind structure are summarized and application of data to the problem of estimating wind forces is discussed. Estimates of maximum wind gusts may be based on the mean windspeed assuming an average turbulent intensity and the windspeed fluctuations are approximately gaussian.

77. Cramer, Owen P., and Robert E. Lynott.
1961. Cross-section analysis in the study of windflow over mountainous terrain. Bull. Am. Meteorol. Soc. 42(10):693-702.

The cross-section charts help in tracing airflow over local obstacles and portray changes in stability. Evidence is given that potential temperature patterns must be considered in the analysis of wind structure in mountain areas.

78. Crosby, John S., and Craig C. Chandler.
1966. Get the most from your windspeed observation. Fire Contr. Notes 27(4):12-13. USDA For. Serv., Washington, D.C.

The probable fastest 1-minute windspeed, the average, and highest momentary gust is given based on observations made at Salem, Mo., during several fire seasons. A table is given to convert from gust windspeed at 5 feet above the ground to the standard 20-foot, 10-minute speed for stable, neutral, and unstable conditions.

79. Cylke, Thomas R.
1978. The destruction of surface based inversions by wind shear turbulence over northern Nevada. Conference on Sierra, Nevada meteorolgy [sponsored by Am. Meteorol. Soc. and USDA For. Serv., South Lake Tahoe, Calif., June 19-21, 1978]. p. 97-100.

The relationship between the Richardson number and the time a temperature inversion breaks up was established. An equation is given expressing the time after sunrise of surface winds greater than 7 knots in terms of the Richardson number.

80. Danard, Maurice.
1977. A simple model for mesoscale effects of topography on surface winds. Mon. Weather Rev. 105:572-581.

A diagnostic, one-level, primitive equation model for computing influences of orography, friction, and heating on surface winds is described. The model works best for orographic channeling. It was applied to Juan de Fuca and Georgia Straits in British Columbia using a grid size of 10 kilometers.

81. Daniels, P. Anders, Bruce E. Palmer, Thomas G. Tarlton, and Thomas A. Schroeder.
1976. A survey of the winds on the Island of Maui for potential wind power generation. part 1: mobile sampling program August 7-26, 1976. 67 p. Dep. Meteorol., Univ. Hawaii.

Maps of surface isotachs and streamlines revealed pronounced diurnal cycles. Diurnal variation in vertical structure also appeared. Physical hypotheses are offered to explain the diurnal patterns.

82. Davenport, A. G.
1961. The spectrum of horizontal gustiness near the ground in high winds. Q. J. Royal Meteorol. Soc. 87(372):194-211.

Describes the spectra of the horizontal components of gustiness in strong winds. Cross-spectra and cross-correlations of velocity between pairs of stations on a mast are given. It appears that cross-spectra can be expressed as a simple function of the ratio of the vertical separation to wavelength.

83. Davidson, Ben.
1963. Some turbulence and wind variability observations in the lee of mountain ridges. J. Appl. Meteorol. 2(4):463-472.

Most turbulent areas occur above the lee slope and are associated with the transition zone between the wind shadow just above the slope and the prevailing flow. The transition zone is usually characterized by sustained vertical gusts that may extend to 3 km downwind of the ridge line. In the valley, the zone of maximum turbulence and wind unrest tends to move to ridge-line height under stable temperature conditions.

84. Davis, Francis K., and Herman Newstein.
1968. The variation of gust factors with mean wind speed and with height. J. Appl. Meteorol. 7(3):372-378.

Gust factors decrease with increasing windspeed, decrease with increasing height, and have no relationship to the temperature lapse rate.

85. Deacon, E. L.
1955. Gust variation with height up to 150 m. Q. J. Royal Meteorol. Soc. 81:562-573.

The increase of gust windspeeds with height is markedly less than that of mean windspeeds. At times of maximums the gust windspeed is approximately proportional to the height raised to the power of 0.085. The corresponding index for mean windspeed is 0.16.

86. Deacon, E. L.
 1973. Geostrophic drag coefficients. Boundary-Layer Meteorol. 5(3):321-340.

Data on the relationship of the surface wind to the geostrophic wind at Parton Down, Salisbury Plain, are presented for various stability conditions and analyzed in light of the Rossby-number similarity theory.

87. Defant, Friedrich.
 1951. Local winds. *In* Compendium of meteorology. p. 655-672. T.F. Malone, ed. Am. Meteorol. Soc., Boston, Mass.

Local winds are considered to be those winds where the friction terms are of the same order of magnitude as the pressure gradient terms and the Coriolis and acceleration terms may be neglected. The range is of the order of 10 km or less. These include land and sea breezes, mountain and valley winds, and jet effect winds. The basic principles of these local winds are discussed.

88. DeMarrais, Gerard A.
 1959. Wind-speed profiles at Brookhaven National Laboratory. J. Meteorol. 16(2):181-190.

A comparison of results obtained through the use of the power law and the logarithmic law shows the former more accurately fits the data. The results are also compared with those obtained at 10 other locations.

89. DeMarrais, Gerard A., George L. Dowing, and Herbert E. Meyer.
 1968. Transport and diffusion of an aerosolized insecticide in mountainous terrain. ESSA Res. Lab. Tech. Memo ARL 6, 46 p. Silver Springs, Md.

Data are presented to serve as a hypothesis on the transport and diffusion mechanisms in and over a forest in mountainous terrain. The general air flow in V-shaped and U-shaped valleys is given. A composite physical model of the temperature structure and air flow was developed.

90. Den Hartog, Gerrit, and Roger H. Shaw.
 1975. A field study of atmospheric exchange processes within a vegetative canopy. *In* Heat and mass transfer in the biosphere. Part 1. Transfer processes in plant environment. p. 299-309. D. A. deVries and N. H. Afgan, eds. Scripta Book Co., Washington, D.C.

Measurements within a mature canopy of corn included mean temperature and windspeed profiles, eddy fluxes, and leaf area density. Direct evaluation of leaf drag and eddy transport coefficients for heat and momentum were obtained. Leaf drag coefficient was nearly constant with height and windspeed. Eddy coefficients were within 30 percent of each other and decreased approximately exponentially with depth in the canopy in a manner similar to the mean wind profile.

91. Denmead, O. T.
 1964. Evaporation sources and apparent diffusivities in a forest canopy. J. Appl. Meteorol. 3(4):383-389.

Measurements of momentum suggest that, even for light winds, transfer processes within the canopy are turbulent in nature and that the level of turbulence is probably associated with momentum transfer.

92. DeVito, Anita, and David R. Miller.
 1977. The effects of corn and oak vegetation on cold air drainage. *In* Weather-climate modeling for real-time applications in agriculture and forest meteorology [preprints from 13th Agric. and For. Meteorol. Conf., Am. Meteorol. Soc., Purdue Univ., West Lafayette, Ind., April 4-6, 1977].

Wind profiles show maximums below and above the canopies. The incident of drainage is higher below the oak canopy when protected from ambient wind mixing. The data plots resemble those of Bergen. Values predicted by two air drainage models were not accurate for airflow beneath the corn and oak canopies.

93. Drake, Ronald L.
 1977. Methods for siting small wind machines. Battelle Pac. Northwest Labs, BNWL-SA-6297, 21 p. Richland, Wash.

The flow of air over rough surfaces and hilly terrain and the technical issues concerning wind energy conversion systems are discussed.

94. Dubov, A. S., and L. P. Bykova.
 1974. Turbulence in forest canopies. Atmos. and Ocean Physics 10(6):650-652.

A nonlinear equation system and the Kolmogorov relations are used to solve the two-layer problem of finding average wind velocity profiles and turbulence characteristics above and within a horizontal homogeneous forest.

95. Durst, C. S.
 1960. Wind speeds over short periods of time. The Meteorol. Mag. 89(1056):181-186.

A statistical assessment is made of windspeeds in short intervals of time. The standard deviation of short period means and the probable value of the maximum windspeed given the mean hourly speed are included.

96. Egan, Bruce A.
 1975. Turbulent diffusion in complex terrain. *In* Lectures on air pollution and environmental impact analysis [sponsored by Am. Meteorol. Soc. Boston, Mass., Sept. 29-Oct. 3, 1975]. Chap. 4 p. 112-135. Duane A. Haugen, workshop coordinator.

The airflow phenomena in regions of complex terrain are discussed. Some examples of model studies of flow are given.

97. Elliott, William P.
 1958. The growth of the atmospheric internal boundary layer. Trans. Am. Geophys. Union 39(6):1048-1054.

An internal boundary layer over a new surface grows as the four-fifths power of distance downwind and is independent of windspeed. The effect of thermal stability is small.

98. Ellsaesser, Hugh W.
 1969. Wind variability as a function of time. Mo. Weather Rev. 97(6):424-428.

Published wind variability data are examined and found to be generally consistent with predictions based on Kolmogorov's similarity hypothesis of locally homogeneous isotropic turbulence.

99. Fichtl, George H., John W. Kaufman, and William W. Vaughan.
 1969. Characteristics of atmospheric turbulence as related to wind loads on tall structures. J. Spacecraft and Rockets 6(12):1396-1403.

A boundary-layer wind model is presented based on Kennedy Space Center data. Peak wind profiles are specified. Empirical formulas are used to estimate gust factors. A special model of turbulence for neutral boundary layer (high windspeeds) accounts for the vertical variation of turbulence power spectra.

100. Finklin, Arnold I.
1973. Meteorological factors in the Sundance Fire Run. USDA For. Serv. Gen. Tech. Rep. INT-6, 46 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.

Strong sustained winds were a major factor in the Sundance Fire Run in northern Idaho on Sept. 1, 1967. The winds were caused by a strong pressure gradient ahead of an approaching trough. Surface winds were around 35 mi/h at exposed ridgetop locations with gusts of 50-55 mi/h in the fire area. Various aspects of the weather situation are examined.

101. Fleagle, Robert G.
1950. A theory of air drainage. J. Meteorol. 7(3):227-232.

Drainage velocity is found to vary periodically about an equilibrium value that is proportional to the net outgoing radiation, and inversely proportional to the cooling height and the slope of the ground. An assumed friction force that is proportional to the square of the velocity gives fairly realistic results.

102. Flemming, G.
1968. Die windgeschumdigkeit auf waldungebenen freiflachen. [The velocity of wind in clearings surrounded by forests.] Archiv Fuorstwes. 17(1):5-16. [Transl. Dep. Fish. For. Can. OOFF-60, 1969, 20 p.]

The mean wind velocity in clearings compared to that in open fields is calculated. Calculations are performed for square and oblong clearings of various sizes and orientation. Many figures showing relative windspeeds are given.

103. Fons, Wallace L.
1940. Influence of forest cover on wind velocity. J. For. 38(6):481-486.

Observations of wind velocity in pine, brush, and grass cover type are offered. Figures and equations descriptive of wind movement in forested country are presented.

104. Fosberg, Michael A.
1967. Numerical analysis of convective motions over a mountain ridge. J. Appl. Meteorol. 6(5):889-904.

The convection associated with a valley wind regime was analyzed by numerical techniques. Numerical simulations reproduced most of the features and processes of the valley wind system. The afternoon quasi-steady state motion of the valley wind results from an apparent maximum rate of conversion of potential to kinetic energy.

105. Fosberg, Michael A.
1969. Airflow over a heated coastal mountain. J. Appl. Meteorol. 8(3):436-442.

Observations of airflow over the Santa Ana Mountains were analyzed by numerical techniques. Flow can be divided into three distinct stages. The first stage is that of valley wind required with ridgetop convection. The second and third stages are associated with flow across the ridge. A wavelike motion is produced in response to the thermal field.

106. Fosberg, Michael A., William E. Marlatt, and Lawrence Krupnak.
1976. Estimating air flow patterns over a complex terrain. USDA For. Serv. Res. Pap. RM-162, 16 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

A 1-layer model of airflow was developed for use in complex terrain. The resultant solutions describe a diagnostic model of the vector flow field. The model can be used in areas with less dense observational networks.

107. Frasier, Alistair B., Richard C. Easter, and Peter V. Hobbs.
1973. A theoretical study of the flow of air and fallout of solid precipitation over a mountain terrain. Part 1. Airflow model. J. Atmos. Sci. 30(5):801-812.

The equation for steady, two-dimensional, laminar inviscid flow over a broad ridge, including latent heat release, is derived. The model indicates the dynamical effects of latent heat are significant in some cases but are generally secondary to the barrier effect of the terrain.

108. Frederick, Ralph H.
1961. A study of the effect of tree leaves on wind movement. Mon. Weather Rev. 89(1):39-44.

Windflow at tree-influenced stations was studied during foliation and defoliation in Nashville, Tenn. It was found to be 25 to 40 percent greater during periods of defoliation.

109. Frenkiel, J.
1962. Wind profiles over hills (in relation to wind-power utilization). Q. J. Royal Meteorol. Soc. 88:156-169.

The wind was investigated at two sites: (1) a hill forming part of a ridge, and (2) an isolated peak. At each site, measurements of vertical gradient, direction, and air temperature gradient up to 40 meters above hilltop for a period of 1 year were obtained and are given.

110. Frenkiel, J.
1963. Gusts over hills (in relation to wind-power utilization). Q. J. Royal Meteorol. Soc. 89(380): 281-283.

Wind gusts over two hills are described. The difference in the ratio of gust variation with height to the mean velocity for the two hills may be linked with differences in the wind ratio and temperature gradient curve.

111. Frenzel, Carroll W.
1962. Diurnal wind variations in central California. J. Appl. Meteorol. 1(3):405-412.

Hodographs of resultants winds at 21 stations for the month of July 1958 are presented. Local topography is most important to airflow in the Bay area. A diurnal circulation is well developed below 1000 meters elevation.

112. Fritschen, Leo J., Charles H. Driver, Charles Avery, and others.
1969. Dispersion of air tracers into and within a forested area: 1. U.S. Army, Atmos. Sci. Lab. ECOM-68-G8-1, 46 p. Fort Huachuca, Ariz.

Objectives, methods, site description, and preliminary results are presented. The site is located in northwest Washington in a regenerated Douglas-fir forest. One objective is to determine the general features of mass and momentum transport at a forest border interface.

113. Fritschen, Leo J., Charles H. Driver, Charles Avery, and others.

1970. Dispersion of air tracers into and within a forested area: 3. U.S. Army, Atmos. Sci. Lab. ECOM-68-G8-3, 53 p. Fort Huachuca, Ariz.

Vegetation density was found to have a strong influence on air flow within the forest. Winds within the forest were not strongly coupled to wind above the forest. Many figures showing windspeed profiles within the forest are given.

114. Fujita, Tetsuya, Kenneth A. Styber, and Roger A. Brown.

1962. On the meso-meteorological field studies near Flagstaff, Arizona. J. Appl. Meteorol. 1(1):26-42.

Statistics of the Elden Mountain wind are discussed. A nocturnal wind at low levels, which greatly resembles the low-level jet wind over the Midwest reported by Blackadar, was discovered. Detailed analysis of a summer storm is given.

115. Furman, R. William, and Glen E. Brink.

1975. The National Fire Weather Data Library: what it is and how to use it. USDA For. Serv. Gen. Tech. Rep. RM-19, 8 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

The library is a collection of daily weather observations from fire weather stations across the nation. Examples are given for using the library on the UNIVAC 1108 computer at the Fort Collins Computer Center.

116. Garratt, J. R.

1977. Review of the drag coefficients over oceans and continents. Mon. Weather Rev. 105:915-929.

Low relief topography and low mountain peaks require a geostrophic drag coefficient of 3×10^{-3}, while land surfaces in general require 2×10^{-3}, for which the drag at 10 meters is 10×10^{-3} and the effective roughness length is approximately 0.2 meters.

117. Gary, Howard L.

1974. Canopy weight distribution affects wind speed and temperature in a lodgepole pine forest. For. Sci. 20(4):369-371.

Windspeeds were minimum and midday temperatures maximum in the midcanopy region where needles and branch weight were concentrated.

118. Geiger, Rudolf.

1966. Das Klima der bodennachen Luftschicht. [The climate near the ground.] Harvard Univ. Press, Cambridge, Mass. [Transl. by Scripta Technica, Inc., 4th. German ed.]

A classic. Examples and discussion of the wind field (and other variables) are given including that in forests and mountains.

119. Gerhardt, J. R.

1962. An example of a nocturnal low-level jet. J. Atmos. Sci. 19(1):116-118.

Observations were obtained from a 1,400-foot tower near Dallas, Tex. The time-height variations of the low-level jet wind are given.

120. Gifford, Frank Jr.

1953. A study of low level air trajectories at Oak Ridge, Tennessee. Mon. Weather Rev. 81(7):179-192.

The properties of low-level airflow, particularly of vertical velocity patterns, are displayed in various ways. Thermal-dynamical slope winds apear to contribute more to these patterns than a purely mechanical effect.

121. Gilman, C. S., and L. L. Weiss.

1950. A numerical solution for irrotational flow over a mountain barrier. Trans. Am. Geophys. Union 31(5):699-706.

The "relaxation method" is applied to Pockel's equation for a case of flow over a given mountain profile. Results are compared to those of others. Different methods give different results, the principal difference being in vertical velocities at higher elevations.

122. Gisborne, H. T.

1941. How the wind blows in the forest of northern Idaho. USDA For. Serv. Prog. Rep., North. Rocky Mt. For. and Range Exp. Stn., 12 p. Missoula, Mont.

Includes a unique set of charts that give the maximum, minimum, and average wind velocities at various heights in an old-age, dense conifer forest stand.

123. Glahn, Harry R.

1970. A method for predicting surface winds. Environ. Sci. Serv. Admin. Tech. Memo. WBTM TDL 29, 18 p. Silver Springs, Md.

Various regression models are discussed and applied to available data. Verification demonstrated usefulness of the objective technique.

124. Gleeson, Thomas A.

1951. On the theory of cross-valley winds arising from differential heating of the slopes. J. Meteorol. 8:398-405.

Expressions are derived for a cross-valley wind. Friction, inertia, the Coriolis force, time of day and year, latitude, orientation of the valley, and inclinations of the slopes are independent variables. Several examples illustrating effects of the independent variables on the wind are discussed.

125. Gleeson, Thomas A.

1953. Effects of various factors on valley winds. J. Meteorol. 10(4):262-269.

A relation is derived for the periodic valley wind as a function of time and elevation, in terms of the diurnal temperature variation, slope of the valley floor, eddy viscosity, the Coriolis force, and a pressure force representing the constraining effect of the valley walls.

126. Gloyne, R. W.

1968. The structure of the wind and its relevance to forestry. *In* Wind effects on the forest. p. 7-1 Supp. to Forestry, J. Soc. For. G.B., Oxford Univ Press.

This paper provides brief comments on: (1) features of large-scale wind systems; (2) surface wind, in particula gales and extreme winds in the British Isles; (3) effects of landscape features on wind near the surface; and (4) effect of surface friction on low-level airflow.

127. Goff, R. C., J. T. Lee, and E. A. Brandes.

1977. Gust front analytical study. U.S. Dep. Trans Rep. FAA-RD-77-119, 126 p. Washington, D.C.

Observations of a gust front evolution associated wi severe thunderstorm are shown. Turbulence and multip surges are discussed.

128. Golding, E. W., and R. I. Harris.

1976. The generation of electricity by wind powe 332 p. John Wiley & Sons, Inc., New York.

Earlier studies of windflow over hills are given chapter 7. Many references are included.

129. Goodwin, William R., Gregory J. McRae, and John H. Seinfeld.
1979. A comparison of interpolation methods for sparse data: application to wind and concentration fields. J. Appl. Meteorol. 18:761-771.

Various techniques were compared using three data sets: (1) a concentration distribution to which the exact solution was known; (2) a potential flow field; and (3) surface ozone measured in the Los Angeles basin. Results indicate that fitting a second-degree polynomial, with each data point weighted according to distance, provides a good compromise between accuracy and computational cost.

130. Grace, J.
1977. Plant response to wind. 204 p. Academic Press: London, New York, San Francisco.

Brings together material scattered among several disciplines. Discusses shelter effects in terms of physiology of plants and the microclimatology of crops. Practical problems of wind damage in agriculture and forestry are discussed.

131. Greene, G. E., H. W. Frank, A. J. Bedard, Jr., and others.
1977. Wind shear characterization. U.S. Dep. Transp. Rep. FAA-RD-77-33, 120 p. Washington, D.C.

Thunderstorm gust front is a major source of low-level wind shear. Several gust front events are analyzed in detail and compared with theoretical models and laboratory studies. Results draw a relationship between gust-front speed of motion and maximum shear.

132. Greenway, M. E.
1978. An analytical approach to wind velocity gust factors. Univ. Oxford Eng. Lab., O.U.E.L. Rep. 1241/78, 44 p.

An equation was derived for determining wind velocity gust factors. The gust factors were found to be linearly dependent on turbulent intensity. Good agreement was found between the predictions of the analysis and measurements made in a wind tunnel.

133. Gurka, James J.
1976. Satellite and surface observations of strong wind zones accompanying thunderstorms. Mon. Weather Rev. 104(12):1484-1493.

The strength of thunderstorm gust fronts can frequently be determined from satellite-derived speed of clouds associated with gust fronts and the appearance of cloud patterns. Rapidly moving gust fronts are associated with strong surface winds. The region of most vigorous convection can be pinpointed by the cloud-edge gradients and appearance of anvil cirrus on enhanced infrared imagery.

134. Hanna, Steven R.
1979. Some statistics on Lagrangian and Eulerian wind statistics. J. Appl. Meteorol. 18(4):518-525.

Reports study of methods of estimating Lagrangian or Eulerian wind fluctuations at one time based on knowledge of wind fluctuations at some previous time. Various concepts were tested using data from Minnesota, Nevada, and Idaho.

135. Hardy, Donald M.
1978. Principle components analysis of vector wind measurements. J. Appl. Meteorol. 17(8):1153-1162.

The method of principal components analysis was generalized to the treatment of vector fields of data and applied to a 12-month record of mean hourly wind velocities from 10 locations in a mesoscale region. Applications of the generalized vector formulation are discussed.

136. Harris, Eugene K., and Robert A. McCormick.
1963. A simple procedure for estimating the standard deviation of wind fluctuations. J. Appl. Meteorol. 2(6):804-805.

A method is derived and tested to estimate the standard deviation of wind fluctuations using amplitude of wind vane fluctuations and the number of wind direction reversals.

137. Hawkes, H. Bowman, and Raymond Wexler.
[n.d.] Local winds: mountain and valley winds, land and sea breezes. 45 p. U.S. Army, Eatontown Signal Lab. Group, Dugway Proving Ground, Tooele, Utah.

A compilation of acceptable theories and facts that pertain to local winds was prepared for forecasters.

138. Hennessey, Joseph P., Jr.
1977. Some aspects of wind power statistics. J. Appl. Meteorol. 16(2):119-128.

The Weibull probability density function is upheld and discussed as a good model for windspeed distributions. The Weibull model is applied to three Oregon windpower sites. It is concluded that the Weibull model has many computational advantages.

139. Hewson, E. Wendell, John E. Wade, and Robert W. Baker.
1977. Vegetation as an indicator of high wind velocity, phase 1. U.S. Dep. Energy, Div. Solar Energy, Final Rep. RLO/2227-T24-77/2, 58 p.

Five different indices of wind effects on trees have been developed and are presently being calibrated in terms of various wind characteristics. Among factors affecting the response of these indicators are exposure, slope, and tree species. Field studies are presently being conducted in the Columbia Gorge and in western Oregon.

140. Hicks, B. B., P. Hyson, and C. J. Moore.
1975. A study of eddy fluxes over a forest. J. Appl. Meteorol. 14(1):58-66.

The zero plane for momentum was located at about d = 0.8h (h is the height of the trees) and the roughness length of the surface was about 30 percent of the difference of (h-d). During daytime, the forest loses heat by turbulence; at night, evaporation continues as heat is supplied by the cooling canopy.

141. Hoecker, W. H., and J. K. Angell.
1969. Effect of a sudden change in terrain height on the three-dimensional low-level air flow, as estimated from tetroon flights. Mon. Weather Rev. 97(12):845-849.

The magnitude of the tetroon height variation is closely related to the magnitude of the height variations of the underlying terrain with tetroon oscillations in the vertical generally preceding the variation in terrain height by a distance exceeding the height of the tetroon above the ground. A maximum upward velocity occurred over land near the shoreline with a compensating downward motion commencing 3 kilometers inland.

142. Holruyd, Edmond W., III.

1970. Prevailing winds on White Fish Mountain as indicated by flag trees. For. Sci. 16(2):222-229.

The direction of branch growth and the position of reaction wood in the trunk tops were studied to determine the direction of prevailing winds. A very complex wind pattern was found.

143. Hsi, G., and J. H. Nath.

1970. Wind drag within simulated forest canopies. J. Appl. Meteorol. 9(4):592-602.

The local drag coefficients, aerodynamic roughness, and wind velocity profiles were studied for a simulated forest and bushy canopy using a wind tunnel. It was found feasible to establish the relationship between model and prototype canopies for flow characteristics.

144. Huang, C. H., and D. L. Drake.

1979. A direct method of adjusting windfield over complex terrain. *In* Fourteenth Conf. on Agric. and For. Meteorol. and Fourth Conf. on Bio-Meteorol. [sponsored by the Am. Meteorol. Soc., Minneapolis, Minn., April 2-6, 1979]. p. 102-104.

A generalized direct method for adjusting wind fields was developed. The mass-consistent model computes wind fields over complex terrain in a terrain conformal coordinate system. The method is expected to reduce formulation.

145. Huss, P. O.

1974. Estimation of distributions and maximum values of horizontal wind speeds. J. Appl. Meteorol. 13(6):647-653.

Statistical analysis suggests that distributions of the ratios of time units (monthly, daily, etc.) to the long-range average windspeeds are similar for different locations. Also, it was found that the distributions of the ratios of the maximum to the average windspeed, or its square root, could be used to estimate expected maxima. Several distributions are shown.

146. Hutte, Paul.

1968. Experiments on windflow and wind damage in Germany; site and susceptibility of spruce forests to storm damage. *In* Wind effects on the forest. p. 20-26. Supp. to Forestry, J. Soc. For. G.B. Oxford Univ. Press.

This paper deals with the influence of topography, including mountain ridges and valleys, and soil on windthrow.

147. Inoue, E.

1963. On the turbulent structure of airflow within crop canopies. J. Meteorol. Soc. Japan 41(6): 317-325.

Canopy-eddy size has been suggested to be constant with height within the canopy layer. Velocities decreased downward following an exponential expression. Vertical transfer coefficients of airflow are discussed and tested with eariler observations.

148. Irwin. John S.

1979. A theoretical variation of the wind profile power-law exponent as a function of surface roughness and stability. Atmos. Environ. 13:191-194.

The variation of the wind profile power-law exponent with respect to changes in surface roughness and atmospheric stability is depicted. Theoretical estimates of the power-law exponent compare favorably with power-law exponent data from various sources.

149. Izumi, Yutaka.

1964. The evolution of temperature and velocity profiles during breakdown of a nocturnal inversion and a low-level jet. J. Appl. Meteorol. 3(1):70-82.

Turbulent mixing appears to play a major role in the breakdown of the observed inversion and in dissipation of the low-level jet wind.

150. Izumi, Yutaka, and Morton L. Barad.

1963. Wind and temperature variations during development of a low-level jet. J. Appl. Meteorol. 2(5):668-673.

Systematic variations of windspeed and air temperature are discussed to illustrate the orderly development of a low-level jet wind and the vertical extent of the mixing process within a deepening inversion.

151. Jackson, Julius Augustus, Jr.

1978. Diurnal variation of wind profiles across mountainous terrain during an air stagnation period. M.S. thesis. N.C. State Univ., Raleigh. 63 p.

Oscillation in lower levels showed the presence of a low-level jet wind. In an easterly flow, the jet reaches a maximum at about 0600 G.M.T. at 300 meters above ground level. The jet is due to an air inertial type oscillation driven by the diurnal variation of friction forces aided by thermal forcing.

152. Jackson, P. S.

1975. A theory for flow over escarpments. *In* Proc., Fourth Int. Conf. on Wind Effects on Buildings and Structures [Heathrow, 1975]. p. 33-39. Keith J. Eaton, ed. Cambridge Univ. Press: London, New York, Melbourne.

An analytical theory for the flow of a fully developed turbulent boundary layer over low two-dimensional humps is described. A particular case of air escarpment is examined in detail.

153. Jackson, P. S., and J. C. R. Hunt.

1975. Turbulent wind flow over a low hill. Q. J. Royal Meteorol. Soc. 101: 929-955.

An analytical solution is presented for the flow of an adiabatic turbulent boundary layer on uniformly rough surface over a two-dimensional hump with small curvature. It is found that, at the point above the top of a low hill at which the increase in velocity is a maximum, the velocity is about equal to the velocity at the same elevation above level ground upwind of the hill. The theory may be useful in giving rough estimates of the effect of hills on wind.

154. Jarvis, P. G., G. B. James, and J. J. Landsberg.

1976. Coniferous forests. *In* Vegetation and the atmosphere, vol. 2, case studies. p. 171-240. J. L. Monteith, ed. Academic Press, New York, London.

This review includes studies and measurements of momentum exchange within forest canopies. Measurements and data are given.

155. Jensen, Niels Otto.

1978. Change of surface roughness and the planetary boundary layer. Q. J. Royal Meteorol. Soc. 104(440):351-356

The ratio between upstream and far downstream surface friction velocities relative to change in surface friction is given on basis of results from the surface Rossby number similarity theory. It is found that even at distances such that the internal boundary layer has grown to the full height of the planetary boundary layer the surface stress still considerably exceeds the equilibrium value.

156. Jensen, Niels Otto, and Ernest W. Peterson.
1978. On the escarpment wind profile. Q. J. Royal Meteorol Soc. 104:719-728.

Various theories for flow over low ridges give results consistent with each other, and these results can be used to quantify certain observed features of the wind profile downwind from an escarpment.

157. Johnson, Glenn T.
1979. Evaluation of schemes for estimating surface wind strength. Atmos. Environ. 13(4):437-442.

Three methods of estimating local surface-wind strength were compared. The methods include: assuming a uniform wind in a region, scaler interpolation between values measured by nearest instruments, and vector interpolation. The concept of the "windiness ratio," the local wind strength as a fraction of that at a reference station, improved the estimates of each method.

158. Johnson, O.
1959. An examination of the vertical wind profile in the lowest layers of the atmosphere. J. Meteorol. 16(2):144-148.

Windspeed increased more rapidly than predicted by the logarithmic law over prairie grass and a snow surface. The data were well represented by a simple power law except under strong inversion conditions. Over short grass, data were represented equally well by the two laws under diabatic and lapse conditions; the power law was better under inversion conditions.

159. Justus, C. G., W. R. Hargraves, Amir Mikhail, and Denise Graber.
1978. Methods of estimating windspeed frequency distributions. J. Appl. Meteorol. 17(3):350-353.

The Weibull function is discussed for representation of windspeed frequency distribution. The Weibull distribution gives smaller root-mean-square errors than the square-root-normal distribution when compared to observed windspeed. Methodology is available for projecting the observed Weibull distribution parameters at anemometer height to another height.

160. Justus, C. G., and Amir Mikhail.
1976. Height variation of windspeed and wind distribution statistics. Geophys. Res. Letters 3(5):261-264.

The power-law profile for windspeed is shown to be consistent with observed height variation of Weibull windspeed probability distribution functions that have been found to fit observed windspeed distributions.

161. Kaimal, J. C., J. C. Wyngaard, Y. Izumi, and O. R. Cote'.
1971. Behavior of spectra and cospectra of turbulence in the atmospheric surface layer. *In* Conf. on Air Pollution Meteorol. of the Am. Meteorol. Soc. [in cooperation with Air Pollution Control Assoc., Raleigh, N. C., April 5-9, 1971]. p. 22-29.

In the inertia subrange, the spectra of u, v, w, and θ velocity components) fall according to a -5/3 power law and the cospectra of uw and wθ according to a -7/3 law. Interpolation formulas are given for the neutral spectra of velocity components, stress, and heat flux.

162. Kawatani, T., and R. N. Meroney.
1970. Turbulence and windspeed characteristics within a model canopy flow field. Agric. Meteorol. 7:143-158.

The study was carried out using roughness elements consisting of wooden pegs 9 cm high. The flow above the canopy was roughly approximated by the logarithmic profile; an exponential velocity profile holds well for the mean velocity within the canopy. The turbulent velocity within the canopy can be represented in exponential form and is related to the mean velocity at the top of the roughness.

163. Kepner, R. A., L. M K. Boelter, and F. A. Brooks.
1942. Nocturnal wind-velocity, eddy-stability, and eddy-diffusivity above a citrus orchard. Trans. Am. Geophys. Union 23:239-249.

The velocity profile above an orchard was approximated by a power function. The night conditions were generally of great stability with the least stability just above tree top where the wind velocity gradient was at a maximum. The values for eddy-diffusivity gave log-log plots.

164. Kerrigan, T. C.
1978. A technique for analyzing the structure of atmospheric turbulence. Battelle Memorial Inst., Pac. Northwest Lab., PNL-2509, 15 p. Richland, Wash.

A technique is devised to assess the contribution of large-scale coherent gust structures to the statistical properties of atmospheric turbulence.

165. Kerrigan, T. C.
1978. A verification statistic for numerical wind models. Battelle Memorial Inst., Pac. Northwest Lab., PNL-2510, 16 p. Richland, Wash.

A generalized wind estimate is computed at certain points in a geographic region. A point-by-point comparison with a numerical model prediction of wind is described. The comparison results in numerical assessments of the probability that the model succeeded in predicting the actual wind field.

166. Kerrigan, T. C.
1978. Spectral estimates of a wind fluctuation statistic pertaining to wind energy generators. Battelle Memorial Inst., Pac. Northwest Lab., PNL-2511, 26 p. Richland, Wash.

An estimate of the frequency with which the volume average of the longitudinal component of wind changes by a given amount in a given time is developed. A general stochastic model is constructed and mathematical foundations stated.

167. Kinerson, R., Jr., and L. J. Fritschen.
1971. Modeling a coniferous forest canopy. Agric. Meteorol. 8:439-445.

A Douglas-fir stand was modeled by normalizing total needle surface area per branch position with respect to the maximum foliage surface area and position in crown. The model canopy was compiled by scaling model crowns to lengths of live crown and surface area representative of trees of respective size classes. The validity of the model was checked by comparing vegetation density with windspeed profiles.

168. Kinerson, Russell S., Jr., and Leo J. Fritschen.
1973. Modeling air flow through vegetation. Agric. Meteorol. 12:95-104.

The authors assumed that the distribution of vegetation density controlled airflow within the forest. This hypothesis was tested by simulating the forest's surface area density distribution with a direct electrical analog computer. Comparison of model-generated and actual flow patterns is presented.

169. Kristensen, L., and H. A. Panofsky.
1976. Climatology of wind direction fluctuations at Risø. J. Appl. Meteorol. 15(12):1279-1283.

Standard deviations of wind direction fluctuations at 76 meters at Risø for the first half year of 1975 have been analyzed as functions of windspeed and temperature lapse rate. For strong winds, the standard deviation variance approaches a constant (about 3.5°). For lower speeds, the variance generally increases with decreasing stability. Largest values are found with weakest winds.

170. Landsberg, J. J., and G. B. James.
1971. Wind profiles in plant canopies. Studies on an analytical model. J. Appl. Ecol. 8:729-741.

Wind profiles measured in a spruce forest and published profiles for maize and an orange orchard are analyzed in terms of an independently derived model. The model fits well only over part of the measured profiles where foliage is not uniformly distributed. Also, the model does not allow separation of the drag coefficient and eddy viscosity terms.

171. Landsberg, J. J., and A. S. Thom.
1971. Aerodynamic properties of a plant of complex structure. Q. J. Royal Meteorol. Soc. 97(414): 565-570.

Coefficients of momentum and vapor transfer of spruce shoots in a wind tunnel were measured and shown to be dependent upon shoot density. Results indicate that the magnitude of the implied shelter effect is the same for water vapor as for momentum.

172. Leahey, Douglas M.
1974. A study of air flow over irregular terrain. Atmos. Environ. 8(8):783-791.

Measurements indicate that air flowing over river banks of moderate slope may parallel the terrain and that turbulence is greater than overregular topography.

173. Lee, R. J.
1975. Objective determination of surface winds in data sparse areas. Environ. Can. Atmos. Environ. Serv., Tech. Memo. TEC 828, 18 p. Downsview, Ont.

A computer program is described that objectively determines surface winds. A combination of theoretical and empirical concepts is utilized, including a dubbing routine to refine the surface pressure field. Some interpretation of the wind field is necessary.

174. Lenschow, Donald H., and Warren B. Johnson, Jr.
1968. Concurrent airplane and balloon measurements of atmospheric boundary-layer structure over a forest. J. Appl. Meteorol. 7(1):79-89.

A strong dependence of horizontal and vertical velocity variances upon stability was found. A clear distinction between the eddy sizes responsible for momentum transport in near-neutral and unstable situations is shown.

175. Leonard, R. E., and C. A. Federer.
1973. Estimated and measured roughness parameters for a pine forest. J. Appl. Meteorol. 12(2):302-307.

The roughness parameter (Z_O) and zero-plane displacement (d) were estimated from canopy map data using Kung's logarithmic formula and Lettau's equation for obstacle size and shape. Assumed values gave Z_O = 138 cm and d = 10.6 meters. Kung's formula gave Z_O = 75 cm and d = 9.7 meters. Measured profiles gave Z_O = 100 cm after d was fixed at a median value of 9.6 meters.

176. Lettau, H. H., and D. A. Haugen.
1961. Wind. *In* Handbook of geophysics, Rev. ed., chap. 5, sec. 1, (5-1) to (5-16). The MacMillan Co., New York.

A good review of the details of wind structure and the probabilities of occurrence of various windspeeds, shears, and gusts. Many tabulated data are included.

177. Leuning, R., and P. M. Attiwell.
1978. Mass, heat, and momentum exchanges between a mature Eucalyptus forest and the atmosphere. Agric. Meteorol. 19(3):215-241.

Zero plane displacement (d), roughness length (Z_O), and friction coefficients were determined from wind profiles under neutral conditions. It was assumed that these parameters were independent of atmospheric stability, and that d may be identified with the height of the mean sink for momentum within the canopy. A common value of d was used in the calculations of the fluxes of momentum, sensible heat, and CO_2.

178. Liu, C. Y., and W. R. Goodin.
1976. An iterative algorithm for objective wind field analysis. Mon. Weather Rev. 104(6):784-792.

Three different methods of analysis are investigated and compared with respect to the degree of minimization of wind divergence and the accuracy of wind data at a measured station. The reduction of wind divergence and the convergence of the iterative scheme are examined.

179. Liu, Mei-Kao, Pravin Mundkur, and Mark A. Yocke.
1974. Assessment of the feasibility of modeling wind fields relevent to the spread of brush fires. Final rep. 21-325, 142 p. Prepared for Forest Fire Lab., Pac. Southwest For. and Range Exp. Stn., Riverside, Calif.

The report includes a general discussion of modeling the wind field, a review of literature including a brief discussion of several different models, and the development of a two-level mesoscale flow model consisting of a fine-grid model embedded in a coarse-grid model. It is concluded that modeling the wind for simulation of fire spread is a realistic goal.

180. Lo, A. K.
1977. Boundary layer flow over gentle curvilinear topography with a sudden change in surface roughness. Q. J. Royal Meteorol. Soc. 103:199-209.

The effect of topography together with a rapid development of an internal boundary layer produced vertical windspeeds that reached a maximum of about 25 percent of the horizontal component. The perturbations due to a smooth-to-rough transition together with an increase of elevation are stronger than those generated from rough-to-smooth transition with a decrease of elevation.

181. Long, Robert R.
1953. Some aspects of the flow of stratified fluids. I. A theoretical investigation. Tellus 5:42-57.

This study relates to the problem of internal oscillations of a fluid in a gravity field with vertical gradients of density of velocity. A criterion is developed giving a sufficient condition for the motion to be uniquely determined by the configuration of the topography over which the fluid moves. Conditions favorable for the formulation of the internal "hydraulic jump" are discussed.

182. Long, Robert R.
1955. Some aspects of stratified fluids. III. Continuous density gradients. Tellus 7(3):341-357.

The results indicate a complicated laminar wave motion for obstacles of maximum height below a certain value. If obstacles are small enough to permit laminar or moderately turbulent motion, the reported experiments verify all important features of theory with remarkable fidelity. Larger obstacles cause considerable turbulence and blocking effects that propagate upstream, causing alternate maxima (jets) and minima of horizontal velocity in the vertical.

183. Lowry, Philip H.
1951. Microclimate factors in smoke pollution from tall stacks. *In* On atmospheric pollution: a group of contributions. Meteorol. Monogr. 1(4):24-29.

Wind direction and windspeed are discussed in terms of the Brookhaven wind gust classification. The classification is applied to the Sutton theory for maximum ground concentration of pollution.

184. Luna, R. E., and H. W. Church.
1974. Estimation of long-term concentrations using a "universal" wind speed distribution. J. Appl. Meteorol. 13(8):910-916.

Windspeed distributions from many diverse sites possess a quasi-universal shape which, when approximated analytically, can be adjusted to yield a distribution of windspeeds that have some specified mean value. The distributions are shown to be satisfactorily described by a lognormal function.

185. Lynott, Robert E., and Owen P. Cramer.
1966. Detailed analysis of the 1962 Columbus Day windstorm in Oregon and Washington. Mon. Weather Rev. 94(2):105-117.

The blowdown of timber in Oregon and Washington amounted to more than 11 million board feet producing long-term problems of fire and insect epidemics. The analysis included isobaric patterns and frontal positions at 1-hour intervals. The pressure pattern is used to determine location and magnitude of maximum winds.

186. McBean, Gordon A.
1968. An investigation of turbulence within the forest. J. Appl. Meteorol. 7(3):410-416.

The intensity of turbulence in a forest is as high as that over open ground. The cospectra of vertical velocity and temperature indicate the shape of the cospectra in the forest may be different from that over open ground. It may be necessary to obtain spatial as well as time averages of the turbulence heat fluxes and the net radiation in order to obtain a good energy balance.

187. McVehil, G. E.
1964. Wind and temperature profiles near the ground in stable stratification. Q. J. Royal Meteorol. Soc. 90:136-146.

Wind and temperature profiles are generally similar when the Richardson number is small. The log-linear wind profile fits observations well for Richardson numbers less than about 0.14. From the log-linear theory, heat flux and surface stress can be calculated given winds at two levels and the surface roughness.

188. Maitani, Toshihiko.
1977. Some turbulence characteristics in the surface layer over a wheat field. Berichte des Ohara Institute fur Landwirtshaftliche Biologie, Okayama Univeristat 17(1):29-46.

Results of a field study of turbulence over a wheat field are reported. The results are generally consistent with results obtained by other investigators.

189. Maitani, T.
1977. Vertical transport of turbulent kinetic energy in the surface layer over a paddy field. Boundary-Layer Meteorol. 12:405-423.

Turbulent kinetic energy and its vertical flux were measured at two heights over a paddy field. Frequent downward transport was found. Contributions to the downward transport arise mainly from the horizontal wind velocity component. Appreciable transport takes place intermittently in a few large downward bursts

190. Maitani, T.
1978. On the downward transport of turbulent kinetic energy in the surface layer over plant canopies. Boundary-Layer Meteorol. 14:571-584.

The mechanism for downward transport of turbulent kinetic energy is investigated. Downward fluxes are predominent just above plant canopies and decrease with increasing height. An explanation is given in order to interpret the turbulent flow structure near plant canopies.

191. Maitani, T.
1978. Vertical transport of turbulent kinetic energy within pine woods. Berichte des Ohara Institute fur Landwirtschaftliche Biologie Okayama Universitat 17(3):159-169.

Wind velocity fluctuations were obtained in a small pine forest to investigate the vertical transport of turbulent kinetic energy. A significant amount of vertical transport was found. Downdrafts were efficient for the downward energy transport within the pine woods.

192. Maitani, T.
1979. An observational study of wind-induced waving of plants. Boundary-Layer Meteorol. 16:49-65.

The motion of individual plants was measured in a wheat field and a rush field. Natural period of oscillation of the plants was found. The frequency responses of displacements of plants to fluctuations of momentum flux are presented.

193. Magata, M., and S. Ogura.
1967. On the airflow over mountains under the influence of heating and cooling. J. Meteorol. Soc. of Japan, Ser. II, 45(1):83-95.

Local strong wind appears under the lee of a mountain when air crosses over the mountain and is cooled by the earth's surface. Convection cells are produced in an unstable layer originating with heating from the ground in daytime. The character of such cells as gravity waves is discussed.

194. Mancuso, Robert Latimer.

1964. On the numerical integration of the steady state equation for air flow over a ridge. M.S. thesis. Univ. Wash., Seattle. 37 p.

The steady state air motion over a mountain ridge was described by solutions to a two-dimensional nonlinear equation of streamline displacement. Computational procedures proved to be stable and converge to unique solutions only when the coefficients satisfied certain restrictive conditions that were generally inconsistent with the assumption of stationary flow.

195. Manins, P. C., and B. L. Sawford.

1979. A model of katabatic winds. J. Atmos. Sci. 36:619-630.

Steady solutions show that katabatic winds are essentially supercritical on all practical slopes and the interfacial stress (between ambient and cooled air layers) due to mixing is the dominant retarding stress.

196. Markee, Earl H., Jr.

1963. On the relationships of range to standard deviation of wind fluctuations. Mon. Weather Rev. 91(1):83-87.

The findings indicate: (1) the wind-direction range shows promise for use as an indicator of the standard deviation of wind direction fluctuations near the ground; and (2) the windspeed range relationships to standard deviation of windspeed are not consistent.

197. Marston, Richard B.

1956. Air movement under an aspen forest and on an adjacent opening. J. For. 54(7):468-469.

Measurements were obtained at about 2 feet above ground in a thick stand of aspen and in rectangular opening about 70 by 200 feet in size. The airflow in the opening averaged 4.57 times that in the stand. On one day, it was 74 times greater. In spring, before the leaves were fully developed, the air movement averaged only 1.4 to 2.0 times greater in the opening. The relative reduction in windspeed under the aspen was 78 percent for the entire measurement period.

198. Martin, H. C.

1971. Average winds above and within a forest. J. Appl. Meteorol. 10(6):1132-1137.

When the atmosphere is stable, variations in wind profile shape above the forest are associated largely with site properties. During the day, variations are less, indicating that convection turbulence tends to control the profile shapes and to mask the effect of site irregularities. The ratio of windspeed in the trunk space to windspeed above the canopy reaches a maximum at noon and drops to 75 percent of its maximum value at night.

199. Marunich, S. V.

1975. Some characteristics of turbulent exchange between a forest and the atmosphere. Soviet Hydrology: Selected Papers. Issue No. 2, p. 51-54.

Analysis of turbulent exchange was based on measurements made in pine and birch forests. Among other findings, the results reveal the existence of a buffer layer above the forest, only above which the main relations of the similarity theory are satisfied.

200. Mason, P. J., and R. I. Sykes.

1978. On the interaction of topography and Ekman boundary layer pumping in a stratified atmosphere. Q. J. Royal Meteorol. Soc. 104(440):475-490.

Numerical results for flow over a two-dimensional ridge confirm theoretical prediction that stratification enhances momentum coupling and produces a low-level jet parallel to the ridge.

201. Mason, P. J., and R. I. Sykes.

1979. Flow over an isolated hill of moderate slope. Q. J. Royal Meteorol. Soc. 105:383-395.

A two-dimensional theory of Jackson and Hunt for turbulent flow over a ridge is extended to three-dimensional topography.

202. Mayhead, G. J.

1973. Some drag coefficients for British forest trees derived from wind tunnel studies. Agric. Meteorol. 12(1):123-130.

Drag coefficients of a variety of commercial conifers 6 to 8 meters tall were determined. The drag coefficients varied within and between species, and with windspeed. Fixed drag coefficients were estimated for use in critical tree-height calculations.

203. Meroney, R. N.

1968. Characteristics of wind and turbulence in and above model forests. J. Appl. Meteorol. 7(5):780-788.

Velocity, turbulence, drag, and gaseous plume spread within a simulated canopy were measured. Several new aspects of flow at the upwind-edge of a forest are displayed.

204. Meroney, R. N.

1970. Wind tunnel studies of the air flow and gaseous plume diffusion in the leading edge or downstream regions of a model forest. Atmos. Environ. 4:597-614.

Flow in the initial fetch region results in a strikingly different streamline motion than within the equilibrium regions. Ventilation of an elevated line source into the canopy region is compared with a simple one-dimensional model.

205. Meroney, R. N., V. A. Sanborn, R. J. B. Bouwmeester, and M. A. Rider.

1976. Sites for wind power installations, wind tunnel simulation of the influence of two-dimensional ridges on windspeed and turbulence. Civil Eng. Dep., Colo. State Univ., Annu. Rep. to ERDA. ERDA/NSF/00702-75/1, 80 p. Fort Collins, Colo.

Measurements were obtained over triangular and sinusoidal shape hills of wind and turbulence. Results are compared with boundary-layer theory. Large overspeed effects over the hills were found. Separation is more pronounced on the sharp crested ridges.

206. Monahan, H. H., and M. Armendariz.

1971. Gust factor variations with height and atmospheric stability. J. Geophys. Res. 76(24):5807-5818.

An increase in gust factors occurs as instability becomes greater and as the mean wind averaging period

enlarged. A decrease in gust factors is associated with an increase in height and windspeed and with an extension of the peak windspeed averaging interval. Tables and figures give average values of gust factors for stable and unstable conditions. Values of average peak gusts or a function of the windspeed are also given.

207. Monteith, John L.

1973. Principles of environmental physics. 241 p. Am. Elsevier Publ. Co., Inc., New York.

Momentum transfer is discussed in chapter 6, pages 78-99. Subjects covered include fetch, skin friction, form drag, and drag on leaves and trees. Wind profiles are discussed, including the behavior of the roughness length and the zero-plane displacement.

208. Mulhearn, P. J.

1977. Turbulent flow over a very rough surface. *In* Sixth Tech. Conf. Austr. Hydraul. and Fluid Mech. [Adelaide, Austr., Sec. 5-9, 1977]. p.269-272.

A wind tunnel investigation was conducted on the variation in mean velocity and Reynolds shear stress above a rough surface. The usefulness of both mean profile and eddy correlation methods for estimating fluxes above a rough terrain is discussed in light of the findings of this study.

209. Mulhearn, P. J.

1979. A note on momentum transfer above very rough surfaces. Q. J. Royal Meteorol. Soc. 105(445):721-723.

Data from wind tunnel experiments on the deviations from unity of the nondimensional velocity gradient ($\emptyset$) close to very rough surfaces are reviewed and compared with field data. It was found for $Z/Z_O < 10^2$ that $\emptyset$ is less than 1 in field data and more than 1 in wind tunnel experiments. The differences are discussed in terms of roughness element flexibility and porosity.

210. Munn, R. E.

1966. Descriptive micrometeorology. 245 p. Academic Press, New York and London.

Gives a general survey of windflow (chap. 7) and turbulence (chap. 8) over homogeneous surfaces.

211. Munro, D. S., and T. R. Oke.

1975. Aerodynamic boundary-layer adjustment over a crop in neutral stability. Boundary-Layer Meteorol. 9:53-61.

An analysis of the modification of the wind profile is based on measurements at four locations extending 100 meters downwind of the leading edge of a mature wheat crop. Boundary-layer growth was rapid, but could be approximated by a four-fifths power of the fetch if a roughness factor is included. Friction velocities are also examined.

212. Myers, Vance A.

1962. Airflow on the windward side of a large ridge. J. Geophys. Res. 67(11):4267-4291.

A theoretical model is developed from which ridgeline winds are computed from data taken at the foot of the ridge. The air is treated as a compressed fluid in laminar two-dimensional flow.

213. Myers, Vance A., and George A. Lott.

1963. Three dimensional wind flow and resulting precipitation in a northern California storm. U.S. Dep. Comm. Weather Bur., Res. Pap. 44, 46 p.

Changes were made in an earlier two-dimensional windflow model by Myers for application to three-dimensional flow.

214. Nappo, C. J., Jr.

1977. Mesoscale flow over complex terrain during the eastern Tennessee trajectory experiment (ETTEX). J. Appl. Meteorol. 16(11):1186-1196.

It is shown that the horizontal averaged flow over the ETTEX region is similar to that over a rough but flat urban area, and that a surface layer of a few hundred meters thickness exists in which the influence of the large-scale topographic features was not felt. During unstable conditions, the horizontal variability of the wind is low and constant with height and tends to be independent of terrain; during stable conditions, the variability is high.

215. Norman, J. M., S. G. Perry, and H. A. Panofsky.

1976. Measurements and theory of horizontal coherence at a two-meter height. Third Symp. on Atmos. Turbulence, Diffusion, and Air Quality [Am. Meteorol. Soc., Raleigh, N.C., Oct. 19-22, 1976]. p. 26-31.

Coherence and phase delay make it possible to pick an optimum position and time delay for estimation of wind fluctuations from measurements elsewhere. An experiment was conducted to evaluate the Panofsky and Mizuno model of horizontal coherence. For unstable conditions, the results agree very well with the theory of Panofsky and Mizuno. Some problems exist under stable conditions.

216. Okulaja, F. Ola.

1968. The frequency distribution of Lagos/Ikeja wind gusts. J. Appl. Meteorol. 7(3):379-383.

The Gumbel distribution provided a good fit to the data reported. The larger the number of observations, the more closely the Gumbel theory tends to apply.

217. Oliver, H. R.

1971. Wind profiles in and above a forest canopy. Q. J. Royal Meteorol. Soc. 97(414):548-553.

For values of the Richardson number of -0.05 and +0.10, the wind profile above the canopy followed a pure log form with measured roughness length increasing linearly from 0.75 to 1.23 meters, respectively. Outside of this stability range, a log-linear profile could be fitted.

218. Oliver, H. R.

1975. Ventilation in a forest. Agric. Meteorol. 14(3): 347-355.

The form of the canopy wind profile can be well approximated by the equation: $U_Z = U_h\ [1 + \alpha\ (1 - Z/h)]^{-2}$ where U_Z and U_h are the windspeeds at height Z and at canopy top height h. The value of the parameter α for most crops lies within the range of 1 to 5. Measured average wind profiles followed the theoretical form with a value of 2.5 to 3.0 irrespective of windspeed. The wind profile in the trunk space showed a bulge under lapse conditions.

219. Oliver, H. R.

1975. Wind speeds within the trunk space of a pine forest. Q. J. Royal Meteorol. Soc. 101:167-168.

Observations show large and frequent fluctuations in windspeed and direction below the canopy. Because the windspeed bulge in the trunk space is found to increase with increasing instability, it seems likely that it may be associated with convective activity.

220. Oliver, H. R., and G. J. Mayhead.
1974. Wind measurement in a pine forest during a destructive gale. Forestry 47(2):185-194.

Wind gusts at top of the canopy during the gale attained 17.5 m/sec. Wind profiles agreed well with the theoretical logarithmic profile above the canopy and the exponential profile below. During the gale, the zero-plane displacement and roughness length values were similar to those at lower speeds. The windspeeds that blew trees down were much lower than those predicted.

221. Orgill, M. M.
1977. Survey of wind measurement field programs. Battelle Pac. Northwest Lab., NNWL Wind-3 UC-60, 53 p. Richland, Wash.

The report identifies and briefly summarizes 139 field programs that have used wind networks. In general, the studies were mesoscale in areal extent. The time period covered is from 1940 to 1977.

222. Orville, Harold D.
1964. On mountain upslope winds. J. Atmos. Sci. 21(6):622-633.

Equations for a two-dimensional thermal initiation problem are used in a numerical study of upslope winds. Two cases are considered, one in a neutral environment, the second in a slightly stable environment. Many of the features of the upslope wind are reproduced in the model.

223. Pandolfo, Joseph P.
1966. Wind and temperature profiles for constant-flux atmospheric boundary layer in lapse conditions with a variable eddy conductivity to eddy viscosity ratio. J. Atmos. Sci. 23(5):495-502.

A set of wind and temperature profile formulas is derived for the constant-flux atmospheric boundary layer in lapse stratification. The derived free-convection wind profile is found to be more consistent with observed wind profiles than other theoretical profiles. Some practical aspects of the use of the profile laws are discussed.

224. Panofsky, H. A.
1963. Determination of stress from wind and temperature measurements. Q. J. Royal Meteorol. Soc. 89(379):85-94.

A form of the diabatic wind profile is used to estimate surface stress from measured winds and temperatures. Excellent estimates of stress can be made, given the roughness length, an estimate of the Richardson number, and an accurate wind measurement at one level.

225. Panofsky, H. A., R. Lipshutz, and J. Norman.
1979. On characteristics of wind direction fluctuations in the surface layer. *In* Fourth Symp. on Turbulence, Diffusion, and Air Pollution of the Am. Meteorol. Soc. [Reno, Nev., Jan. 15-18, 1979]. p. 1-4.

Wind fluctuations over rolling terrain are compared to those over flat and uniform terrain. Measurements were made 2 meters above ground with very few exceptions. The ratio of the standard deviation of wind fluctuations to the windspeed is less over flat terrain than over rolling terrain.

226. Panofsky, H. A., D. Sullivan, D. W. Thomson, and D. Moravek.
1973. Coherence between windspeed fluctuations over Lake Ontario. *In* Third Conf. on Probability and Statistics in Atmospheric Science [Boulder, Colo., June 19-22, 1973]. p. 274-276. Am. Meteorol. Soc.

Preliminary measurements of the coherence decay parameter have verified a theoretical hypothesis relating the decay parameter to the level of turbulence. Studies of the predicted and observed phase differences suggest that eddies larger in scale than the surface-to-anemometer height are translated at a velocity slightly greater than that of the mean windspeed.

227. Panofsky, H. A., and A. A. Townsend.
1964. Change of terrain roughness and the wind profile. Q. J. Royal Meteorol. Soc. 90(384):147-155.

The authors theorize that only the air below an internal boundary is affected by a terrain roughness change and that the air above the boundary is still moving with the speed and stress that it had upwind of the change. A fairly sharp boundary separates the air and, for micrometeorological distances, the slope of the interface is of the order of 1/10.

228. Pendergast, M. M., and T. V. Cawford.
1974. Actual standard deviations of vertical and horizontal wind direction compared to estimates from other measurements. *In* Symp. on Atmos. Diffusion and Air Pollution of the Am. Meteorol. Soc. [cosponsored by the World Meteorol. Organ., Santa Barbara, Calif., Sept. 9-13, 1974]. p. 1-6.

Meteorological data collected near the Savannah River in South Carolina were used to assess the applicability of several techniques to determine horizontal and vertical wind fluctuations. The errors caused by the use of a temperature profile are greater than those involved in calculating the standard deviation of fluctuations directly from measurements of the fluctuation angles.

229. Perrier, E. R., J. M. Robertson, R. J. Millington, and D. B. Peters.
1972. Spatial and temporal variation of wind above and within a soybean canopy. Agric. Meteorol. 10(6):421-442.

Wind profile measurements within the crop canopy are consistent with a two-dimensional flow field. The turbulent length scale describes the long, thin types of "eddies" flowing within the turbulent boundary layer above the crop canopy. The probability distributions of wind velocity were largely non-Gaussian.

230. Perry, Steve G., John M. Norman, Hans. A. Panofsky, and J. David Martsolf.
1978. Horizontal coherence decay near large mesoscale variations in topography. J. Atmos. Sci. 35(10):1884-1889.

Measurements of turbulence were made at 2 meters above the surface. A good correlation has been found between the variance spectrum of the lateral (crosswind) velocity component and an estimate of the lateral Euleriar scale of the longitudinal velocity component. The presen data compare favorably with an earlier theoretical model.

231. Peterson, Ernest W., and Neils E. Busch.
1978. The effect of local terrain irregularities or the mean wind and turbulence characteristic: near the ground. *In* WMO Symp. on Boundary Layer Physics Applied to Specific Problems o

Air Pollution [Norrköping, June 19-23), 1978]. WMO - No. 510, p. 45-50. World Meteorol. Organ., Geneva.

This paper presents a review of findings of a field program conducted at Risø, Denmark, to test models of airflow over a change in surface roughness.

232. Peterson, Ernest W., Niels Otto Jensen, and Jørgen Hostrup.

1979. Observations of downwind development of windspeed and variance profiles at Bognaes and comparison with theory. Q. J. Royal Meteorol. Soc. 105(445):521-529.

Observations of atmospheric flow over a change in surface roughness are reported. Both windspeed and turbulence were measured. It was found that the predictions of second-order closure models are consistent with the observed flow.

233. Peterson, Ernest W., Leif Kristensen, and Chang-Chun Su.

1976. Some observations and analysis of wind over non-uniform terrain. Q. J. Royal Meteorol. Soc. 102(434):857-869.

Wind measurements were made from the surface to a height of 12 meters over a distance of 150 meters. The variation in the elevation of the underlying terrain has a larger effect than that of the variation in surface roughness. The shape of the downwind profile is consistent with the prediction of the second-order closure change of roughness models.

234. Petit, C., M. Trinite, and P. Valentin.

1976. Study of turbulence diffusion above and within a forest - application in the case of SO_2. Atmos. Environ. 10(12):1057-1063.

Some results concerning characteristics of airflow within and above a forest are presented. These include horizontal mean windspeed profiles, turbulent intensities, turbulent transfer coefficients, autocorrelation curves, energy spectra, turbulent scales, and microscales.

235. Petkovsek, Z., and H. Hocevar.

1971. Night drainage winds. Arch. Met. Geoph. Biokl. Serv. A, 20:353-360. [In English.]

Presents a model of drainage winds given wind velocity as a function of the following parameters: net radiation, friction coefficients, slope, and environmental lapse rate.

236. Petkovsek, Z., and M. Ribaric.

1965. On the airflow over mountains with gentle slopes. Tellus 17(4):443-448.

Nonlinear equations for the two-dimensional, small-scale, steady-state flow of a compressible fluid are put in a form appropriate for the treatment of streamlines with gentle slopes. The equations are solved numerically and examples are given to demonstrate the difference between solutions obtained by linearized and nonlinearized models.

237. Petzold, D. E., and S. Kelly.

1975. The effect of woodland and elevation on winds in the Schefferville area. McGill Univ., Dep. Geophys., Climatol. Bull. 18, 18 p. Montreal, Can.

Wind measurements were made at eight different sites varying in elevation and exposure. A linear relationship exists between each site and a reference site. To account for the modifying effect of vegetation, and empirical density number was used depending upon the presence of a tree barrier or a few shrubs, and for a dense cover of shrubs. The barrier effect and the effect of elevation on wind at particular sites is discussed.

238. Plate, Erich J.

1971. Aerodynamic characteristics of atmospheric boundary layers. 190 p. U.S. Atomic Energy Comm., Div. Tech. Infor. Oak Ridge, Tenn.

This report presents a summary of mean-flow conditions in the planetary boundary layers.

239. Plate, Erich J.

1971. The aerodynamics of shelter belts. Agric. Meteorol. 8(3):203-222.

How the interaction of aerodynamic factors shapes the velocity distribution in the shelter region is discussed qualitatively. Emphasis is on the region directly downwind from the shelter. Some conclusions are drawn to research needs for improving the understanding of shelter belts aerodynamics

240. Plate, Erich J., and A. A. Quaraishi.

1965. Modeling of velocity distributions inside and above tall crops. J. Appl. Meteorol. 4(3):400-408.

A model crop consisting of flexible plastic strips was investigated by means of a low-speed wind tunnel. Results indicate that some distance (X_0) downstream from the edge of the model crop, wind profiles in and above the crop reach an equilibrium state. The length X_0 is discussed. Results are compared with field studies.

241. Pockels, F.

1901. The theory of the formation of precipitation on mountain slopes. Mon. Weather Rev. 21:152-159. [Transl. from Ann. d. Physik, 1901(4), vol. III, p. 459-480.]

A theory of inviscid flow over mountainous terrain is discussed. Solutions to velocity potential equations are found considering a series of assumptions. Streamline flow is used to specify the contour of the ground. An example of flow over an idealized mountain range is given.

242. Pooler, F., Jr.

1963. Airflow over a city in terrain of moderate relief. J. Appl. Meteorol. 2(4):446-456.

The flow during stable hours appeared to be approximately antitriptic. The pressure forces consisted of both large-scale and local components. Flow at levels removed from surface friction tends to show an initial oscillation about the geostrophic wind. The flow at any particular level above the valley floor should depend on the large-scale gradient and the orientation and height of topographic barriers to the flow.

243. Poppendiek, H. F.

1951. Gustiness profiles in the lower layers of the atmosphere. *In* On atmospheric pollution. Meteorol. Monogr. 1(4):36-38.

Two sets of gustiness profiles in the lower layers of the atmosphere under a range of stability conditions are presented. One set was obtained over an Arizona desert and the other over Los Angeles. Some interpretations of the diurnal variation of the gustiness are given.

244. Ramsdell, J. V.

1978. Estimates of the number of large amplitude gusts. Battelle Pac. Northwest Labs, PNL-2508, 44 p. Richland, Wash.

The number of large amplitude gusts per year is treated as a function of the annual mean windspeed and terrain roughness. The treatment is based upon the assumption that the atmosphere has neutral stability during high winds. Results are presented in tabular form as a function of gust amplitudes and hourly average windspeed.

245. Ramsdell, J. V.

1978. Wind shear fluctuations downwind of large surface roughness elements. J. Appl. Meteorol. 17(4):436-443.

Wind shear fluctuations are described by a Pearson Type IV probability distribution. Models are presented for the standard deviation, skewness, and kurtosis of the distributions.

246. Randall, J. M.

1969. Wind profiles in an orchard plantation. Agric. Meteorol. 6(6):439-452.

Vertical wind profiles between 6 and 40 feet height were obtained in an orchard with trees of crown diameter 13 feet; height, 12 feet; and spacing of 24 feet. The horizontal attenuation of wind was large for the first three to four tree rows beyond which a linear decrease of wind was observed. Vertical wind profiles were fitted to a logarithmic profile. No significant relationship between profile parameters and atmospheric stability was found.

247. Rao, K. S., J. C. Wyngaard, and O. R. Cote'.

1974. The structure of the two-dimensional internal boundary layer over a sudden change of surface roughness. J. Atmos. Sci. 31(3):738-746.

The effects of an abrupt change of surface roughness in the mean flow are investigated by means of a closed system of equations together with specified boundary conditions. The distributions of wind shear, mixing length scales, and ratio of stress to turbulent kinetic energy are shown to differ significantly from their equilibrium flow variations.

248. Rauner, Ju. L.

1976. Deciduous forest. *In* Vegetation and the atmosphere, vol. 2. Case studies. Chap 8, p. 241-264. S. L. Monteith, ed. Academic Press, New York, London.

The essential characteristics of the micrometeorological regime of deciduous forests are presented including the aerodynamic characteristics of leaf canopies.

249. Raupach, M. R.

1979. Anomalies in flux-gradient relationships over forest. Boundary-Layer Meteorol. 16(4):467-486.

Results show that the values of vertical turbulent diffusivity momentum (K_M) over a forest are not significantly different from those predicted by semiempirical diabatic influence functions appropriate to smoother surfaces such as short grass. However, the values for heat (K_H) and water vapor transfer (K_E) exceed their predicted values by an average factor of 2. Methods are given to account for the K_H and K_E anomalies.

250. Raynor, Gilbert S.

1971. Wind and temperature structure in a coniferous forest and a contiguous field. For. Sci. 17(3):351-363.

Data collected over a 5-year period are presented. Wind was measured at three to seven heights and five locations in and above 10.5-meter pine forest and at four heights in a nearby field. Data were classified with respect to wind direction relative to the forest edge, windspeed, gustiness, and cloudiness. At the forest edge, windspeed in the trunk space was greater than in the canopy for a distance of about 60 meters. With a longer fetch through the forest, speeds varied little with height to midcanopy.

251. Read, Ralph A.

1964. Tree windbreaks for the central Great Plains. USDA For. Serv. Agric. Handb. 250, 68 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

The effects of tree height, density, barrier width, and wind velocity are given. Many figures illustrate the windbreak effect. The barrier shown in figure 5, p. 5, is wide enough (15 tree heights) to use the data to estimate the sheltering effect downwind of the lee edge of a forest.

252. Reed, Jack W.

1978. Windspeed distribution changes with height at selected weather stations. Sandia Laboratories, SAND 76-0714, 54 p. Albuquerque, N. Mex.

Ten-year records of hourly windspeed observations at 15 selected weather stations are presented. Windspeed distribution curves and tables of synthesized time series have been prepared.

253. Reifsnyder, William E.

1955. Wind profiles in a small isolated forest stand. For. Sci. 1(4):289-297.

A fully developed "infinite stand" profile probably occurred at 250 feet from the forest edge under lapse conditions. Under inversion conditions, the wind profile reached its full development nearer the edge. Maximum attenuation of wind by tree crowns was 50 to 60 percent during lapse conditions and 60 to 70 percent during inversion conditions. Greater percent reduction occurred with stronger winds.

254. Rider, Laurence J.

1966. Low-level jet at White Stands Missile Range. J. Appl. Meteorol. 5(3):283-287.

A low-level wind maximum frequently observed at White Sands is often supergeostrophic and associated with large values of wind shear. The jet is predominantly a nocturnal phenomenon with the nose of the profile usually near the height of the nocturnal temperature inversion. There were cases in which a temperature inversion developed during the night, but a significant low-level wind maximum was not evident.

255. Roth, Rainer.

1971. Turbulence spectra with two separated regions of production. J. Appl. Meteorol. 10(3):430-432.

The observed spectra of turbulent energy in forests and the free atmosphere show a "hump" that may be explained by a process producing energy in a region where existing turbulent energy, produced at lower wavelengths, is cascaded.

256. Rutter, N.

1968. Geomorphic and tree shelter in relation to surface wind conditions, weather, time of day and season. Agric. Meteorol. 5(5):319-334.

Mean hourly windspeeds at 4 feet height on 15 sites in varying topography were recorded for a year. Results show how physical factors affect wind exposure and allow some general conclusions on geomorphic shelter.

257. Ryan, Bill C.

1977. A mathematical model for diagnosis and prediction of surface wind in mountainous terrain. J. Appl. Meteorol. 16(6):571-584.

A model was developed on the premise that mountain winds are the result of vector addition of different wind components. The components include valley-mountain wind, slope wind, sea-land breeze, larger scale wind, and sheltering and diverting effect of topography. Model-generated winds are compared to observed winds.

258. Ryan, Bill C., and J. Gregory Brown.

1978. Influences on wind in mountainous terrain. *In* Conf. on Sierra Nevada Meteorology [sponsored by the Am. Meteorol. Soc. and the USDA For. Serv., South Lake Tahoe, Calif., June 19-21, 1978]. p. 46-52.

Analysis of daytime and nighttime winds obtained at eight stations during summer months shows that the winds tend to switch directions from day to night in mountains. The reversal may not be 180 degrees, but depends upon canyon conditions.

259. Sacre', C.

1979. An experimental study of the airflow over a hill in the atmospheric boundary layer. Boundary-Layer meteorol. 17(3):381-401.

Wind measurements were obtained along the slope of a 100-meter high hill with an average slope of 8 percent. Near the ground, local topographic effects and inhomogeneous roughness along the slope have the same effect as the mean slope of the hill. The overspeed is proportional to the upwind slope, but the turbulent structure does not seem to be disturbed by the hill.

260. Sadeh, Willy Z.

1975. Simulation of flow above forest canopies. *In* Heat and mass transfer in the biosphere, part I. Transfer processes in the plant environment. p. 251-263. D. A. deVries and N. H. Afgan, eds. Scripta Book Co., Washington, D.C.; John Wiley & Sons, New York.

The similarity criteria for achievement of wind-tunnel simulation of forest canopy flow are discussed. A forest canopy model was used to investigate upper-canopy flow. Mean velocity distributions are presented.

261. Sadeh, W. Z., J. E. Cermak, and T. Kawatani.

1971. Flow over high roughness elements. Boundary-Layer Meteorol. 1:321-344.

The results of a wind tunnel model study indicate that the flow may be divided into transition and fully developed regions, followed by a short adjustment near the downstream terminus of a rough boundary. The transition region has a strong effect in the flow characteristics within and above the layer of roughness elements. Generally, the roughness zone influence extends to more than three times the roughness height.

262. Sauer, Fred M., Wallace L. Fons, and Keith Arnold.

1951. Experimental investigation of aerodynamic drag in tree crowns exposed to steady wind-conifers. 19 p., mimeo. USDA For. Serv., Div. For. Fire Res., Washington, D.C.

The analysis of wind tunnel and field work is given. Variation of tree crown drag was due primarily to bending which results from the application of drag forces. Data were reduced to a set of dimensionless functional relationships that are different for each species tested; however, the general characteristics are the same.

263. Scholtz, M. T., and C. J. Brouckaert.

1978. Modeling of stable air flow over a complex region. J. Appl. Meteorol. 17(9):1249-1257.

A linear model is achieved by assuming the coupling between the motion of surface air and the overlying geostrophic wind is through a pressure gradient. The two-dimensional, steady state, potential flow model takes into account the land breeze, slope and valley, and synoptic-scale pressure gradient.

264. Schroeder, Mark J.

1960. Exploratory fire climate surveys on prescribed burns. Mon. Weather Rev. 88(4):123-129.

Local wind patterns, which are extremely complex, appear to be made up of several circulations of different size scales. Results include finding an increase of wind blowing out of a lee side of a fire and a down-canyon afternoon wind. Actual fire behavior was close to that indicated by the observed wind patterns.

265. Schroeder, Mark J., and Charles C. Buck.

1970. Fire weather -- a guide for application of meteorological information to forest fire control operations. USDA For. Serv. Agric. Handb. 360,229 p. (reprinted 1977). U.S. Gov. Print. Off., Washington, D.C.

A descriptive, illustrative discussion of the weather factors related to fire control planning and action. Surface wind is covered in chapter 6 (general winds) and chapter 7 (convective winds). The use of technical terms is kept to a minimum.

266. Scorer, R. S.

1956. Airflow over an isolated hill. Q. J. Royal Meteorol. Soc. 82:75-81.

The perturbation theory is used to compute the vertical displacement of a uniform airstream passing over a solitary hill of circular and oval shape. Diagrams show contours of the vertical displacement at four different heights above the theoretical hills.

267. Seginer, I., and P. J. Mulhearn.

1978. A note on vertical coherence of streamwise turbulence inside and above a model plant canopy. Boundary-Layer Meteorol. 14(4):515-523.

Measurements of longitudinal turbulent velocity were made inside and above a model plant canopy in a wind tunnel. It was found that above the zero-plane displacement level, the coherence and phase results were similar in many respects to atmospheric data, but deviations appeared deeper in the model canopy.

268. Shaw, Roger H.

1977. Secondary wind speed maxima inside plant canopies. J. Appl. Meteorol. 16(5):514-521.

Increased windspeeds within the lower portions of vegetative canopies can be accounted for by one-dimensional vertical transport of momentum through the denser upper foliage. Within a suitable framework, the windspeed bulge in the lower levels can be explained by application of a one-dimensional model.

269. Shaw, R. H., R. H. Silversides, and G. W. Thurtell.
1974. Some observations of turbulence and turbulent transport within and above plant canopies. Boundary-Layer Meteorol. 5(4):429-449.

Shear stress was measured directly within a vegetation canopy. The power spectra of velocity above a forest canopy obeyed a -5/3 power relation. Isotropy was present above a pine forest.

270. Shaw, Roger H., David P. Ward, and Donald E. Aylor.
1979. Frequency of occurrence of fast gusts of wind inside a corn canopy J. Appl. Meteorol. 18(2): 167-171.

A probability density distribution of the total wind and of the change in windspeed were determined. Gusts of wind with speeds exceeding the local mean wind by a factor of 3 or more were frequent near the middle of the canopy.

271. Sherlock, R. H.
1951. Analyzing winds for frequency and duration. *In* On atmospheric pollution. Meteorol. Monogr. 1(4):42-49.

A means is devised to estimate the frequency and duration of future winds above critical values at a given site.

272. Sherlock, R. H.
1953. Variations of wind velocity and gusts with height. Am. Soc. Civil Eng. Trans. 118:463-488.

Airflow over level open country is considered. The 1/7 power law is a sufficiently close approximation to the variation of wind velocity up to 1,000 feet, above which a constant velocity is justified. Gust factors are proportional to the inverse ratio of height raised to the 0.0625 power.

273. Sherman, Christine A.
1978. A mass-consistent model for wind fields over complex terrain. J. Appl. Meteorol. 17(3):312-319.

A model was developed where interpolated three-dimensional mean winds were adjusted in a weighted least-squares sense to satisfy continuity. The upper and lateral boundaries above topography were assumed to be open air; the bottom boundary was determined by the topographic elevations of the area studied.

274. Shinn, Joseph Hancock.
1971. Steady state two-dimensional air flow in forests and the disturbance of surface layer flow by a forest wall. Ph.D. thesis. Univ. Wis., Madison. 91 p.

The study provides models of the mean momentum transport processes in and above forests, for the equilibrium flow in forests, and for the nonequilibrium airflow in the transition region. The study is confined to neutral stability conditions.

275. Shir, C. C.
1972. A numerical computation of air flow over a sudden change of surface roughness. J. Atmos. Sci. 29(2):304-310

A set of equations governing flow over a roughness change is solved by a finite-difference method. A turbulent energy equation is included. Two boundary layers; a velocity layer and a stress layer, are found.

276. Shukla, J., and K. R. Saha.
1974. Computation of non-divergent stream-function and irrotational velocity potential from the observed winds. Mon. Weather Rev. 102(6): 419-425.

An iterative scheme is presented to compute the stream function and velocity potential. A wind field can be reconstructed from the computed fields of stream function and velocity potential.

277. Sigl, Arden B., Ross B. Corotis, and Danny J. Won.
1979. Run duration analysis of surface wind speeds for wind energy application. J. Appl. Meteorol. 18(2):156-166.

A model is developed for distribution of windspeed persistence above and below fixed reference speeds. It is possible to interpret the model in terms of a single parameter that can be calibrated from the mean seasonal windspeed at a site.

278. Simard, A. J.
1971. Calibration of surface wind observations in Canada. For. Fire Res. Inst., Inf. Rep. FF-X-30, 19 p. Ottawa, Ont.

A procedure is outlined whereby surface observations can be used to obtain area averages. A map showing windspeeds across Canada, which can be used to calibrate any station, is also presented.

279. Singer, Irving A., and Maynard E. Smith.
1953. Relation of gustiness to other meteorological parameters. J. Meteorol. 10:121-126.

A gustiness classification is defined by the range and appearance of the horizontal wind direction trace. Seasonal and diurnal variations are presented.

280. Skibin, D.
1974. Variation of lateral gustiness with windspeed. J. Appl. Meteorol. 13(6):654-657.

Observations show a decreasing trend of lateral direction fluctuations with increasing windspeed above 2 miles per second. For low windspeeds (less than 2mi/sec), direction fluctuations increased with increasing windspeed durin stable and unstable conditions.

281. Slade, David H., ed.
1968. Meteorology and atomic energy 1968. 445 p. U.S. Atomic Energy Comm./Div. Tech. Inf., Oak Ridge, Tenn.

Some basic principles of meteorology are presented including the local wind structure. Includes textbook knowledge as well as handbook type aids in the form of equations and graphs.

282. Slade, David H.
1969. Wind measurements on a tall tower in rough and inhomogeneous terrain. J. Appl. Meteorol. 8(2):293-297.

Windspeed profiles and the standard deviation of the horizontal wind direction distribution at an irregular site differ quite radically depending on the local upwind terrain.

283. Small, R. T.
1957. The relationship of weather factors to the rate of spread of the Robie Creek fire. Mon. Weather Rev. 85(1):1-8.

On four of five days, the fire followed patterns previously recognized as being usually associated with prevailing weather conditions. One of those days was an example of a long fire run resulting from a strong and persistent horizontal wind.

284. Smedman-Hogstrom, Ann-Sofi, and Ulf Hogstrom.
1978. A practical method for determining wind frequency distributions for the lowest 200 m. from routine meteorological data. J. Appl. Meteorol. 17(7):942-954.

A model is used to calculate the rate of growth of internal boundary layers resulting from discontinuities in roughness as well as the shape of the wind profile in various layers. Shape characteristics of the profile are determined as a function of roughness length and stability.

285. Smith, F. B., and P. F. Abbott.
1961. Statistics of lateral gustiness at 16 m. above ground. Q. J. Royal Meteorol. Soc. 87(374):549-561.

Many wind observations were obtained. The hourly average values of the standard deviation of wind fluctuations ($\alpha_{\emptyset}$) are classified according to windspeed and stability. A critical value of stability is indicated for which $\alpha_{\emptyset}$ depends either on stability or the windspeed. Tables and figures giving values of $\alpha_{\emptyset}$ as a function of stability and wind for various sampling periods are presented.

286. Smith, F. B., D. J. Carson, and H. R. Oliver.
1972. Mean wind-direction shear through a forest canopy. Boundary-Layer Meteorol. 3(2):178-190.

The equations of motion applying to the wind field in a forest canopy are simplified to a balance between the shearing stress gradient and either the form-drag of the leaves in the upper dense canopy or the overall horizontal pressure gradient in the more open space beneath. Results indicate that, in descending through the forest, the stress and wind vectors turn through an angle that depends on the forest characteristics and on the stability and the speed of the airflow above the forest.

287. Smith, Maynard E.
1951. The forecasting of micrometeorological variables. *In* On atmospheric pollution. Meteorol. Monogr. 1(4):50-55.

A forecasting program for the Brookhaven National Laboratory is discussed in some detail. The technique is based on empirical relationships between synoptic and micrometeorological variables. Considerable attention is given to the classification and prediction of horizontal gustiness.

288. Sommers, William T.
1976. On the relationship between LFM predictions, on site rawinsonde observations and surface flow in mountainous terrain. *In* Sixth Conf. on Weather Forecasting and Analysis [Albany, N.Y., May 10-14]. p. 141-145. Am. Meteorol. Soc., Boston, Mass.

The limited fine mesh (LFM) forecasts by the National Weather Service can predict synoptic scale forcing of the boundary-layer and surface flow with acceptable accuracy in mountainous terrain.

289. Stanhill, G.
1969. A simple instrument for the field measurement of turbulent diffusion flux. J. Appl. Meteorol. 8(4):509-513.

The relationship between the zero-plane displacement (d) and vegetation height (h) is given. The results agree completely with the relationship d = 0.64h derived earlier by Cowan.

290. Sterns, Charles R., and Heinz H. Lettau.
1963. Report on two wind profile modification experiments in air flow over the ice of Lake Mendola. *In* Studies of the effect of variations in boundary conditions on the atmospheric boundary layer. p. 115-138. Univ. Wis., Madison, Dep. Meteorol., Annu. Rep. 1963.

Two different wind profile modification experiments, employing an array of conifer saplings (Christmas trees) and bushel baskets, were made in late winter. An analysis of the results is presented in terms of horizontal momentum budgets as a function of wind fetch across and downwind of the obstacles

291. Stewart, Dorathy A., and Osker M. Essenwanger.
1978. Frequency distribution of wind speed near the surface. J. Appl. Meteorol. 17(11):1633-1642.

The Weibull distribution provides a good analytical approximation to the cumulative distribution. Two methods of fitting a Weibull distribution with a nonzero location parameter are discussed. The three-parameter model is better than the two-parameter model for predicting extreme values.

292. Sutton, O. G.
1953. Micrometeorology: a study of physical processes in the lowest layers of the earth's atmosphere. 333 p. McGraw-Hill Book Co., Inc., New York, London.

A basic text of micrometeorological processes including fluid flow and the problems of wind structure near the earth's surface.

293. Swanson, R. N., and H. E. Cramer.
1965. A study of lateral and longitudinal intensities of turbulence. J. Appl. Meteorol. 4(3):409-417.

The lateral and longitudinal intensities decrease with height in all thermal stratification that can be expressed in terms of a power law. The turbulent intensity at all heights tends to be universally proportional to the mean wind. Tables and figures showing values of the standard deviation of wind direction as a function of height, stratification, and windspeed are given.

294. Szeicz, G., D. E. Petzold, and R. G. Wilson.
1979. Wind in the subarctic forest. J. Appl. Meteorol. 18:1268-1274.

Windspeeds were measured at 2 - mile height in open lichen woodlands and were related to standard winds recorded at a local airport site. The reduction in wind is related to tree height, stand density, and shrub cover.

295. Tajchman, S. J.
1973. On vertical velocity profiles of meteorological parameters above a layer of rough vegetation. J. Geophys. Res. 78(27):6381-6385.

Profiles of windspeed and other parameters were measured above a pine forest. In addition to possible practical applications, the Monin-Obukhov formulas can be used to interpret the meteorological processes.

296. Takle, E. S., and J. M. Brown.
1978. Note on the use of Weibull statistics to characterize windspeed data. J. Appl. Meteorol. 17(4): 556-559.

A hybrid density function is given for describing windspeed distribution having nonzero probability of calm. A Weibull probability graph is used to determine distribution parameters.

297. Tattleman, Paul.
1975. Surface gustiness and windspeed range as a function of time interval and mean windspeed. J. Appl. Meteorol. 14(7):1271-1276.

The gust factor (peak wind divided by the steady wind) can be used to describe the relationship between mean windspeed and windspeed range for a specific interval of time. Results are applicable to smooth locations at a height of approximately 15 meters above the surface.

298. Taylor, Dee F., and Dansy T. Williams.
1967. Meteorological conditions of the Hellgate fire. USDA For. Serv. Res. Pap. SE-29, 12 p. Southeast. For. and Range Exp. Stn., Asheville, N.C.

High temperatures, low humidities, and strong winds produced a condition of extreme fire danger. Large-scale negative divergence and positive vorticity of the surface wind occurred. These favored intensification of the fire.

299. Taylor, P. A.
1969. On planetary boundary layer flow under conditions of neutral thermal stability. J. Atmos. Sci. 26(3):427-431.

A wind spiral model is used to represent the flow above a surface of uniform roughness. Test of the model is inconclusive, perhaps due to surface inhomogeneity.

300. Taylor, P. A.
1969. The planetary boundary layer above a change in surface roughness. J. Atmos. Sci. 26(3):432-440.

A mixing length model is used to study turbulent airflow under conditions of neutral stability. Numerical solutions are given to a parabolic system of partial differential equations. The case of flow above a step change in surface roughness is solved. A very long fetch is required for equilibrium flow to exist above the new surface. In particular, surface wind direction adjusts very slowly.

301. Taylor, P. A.
1970. A model of airflow above changes in surface heat flux, temperature and roughness for neutral and unstable conditions. Boundary-Layer Meteorol. 1(1):18-39.

Results indicate large increases in shear stress at the outer boundary of the internal boundary layer for airflow with neutral upstream conditions encountering a step change in surface temperature with no roughness change. Other situations are investigated.

302. Taylor, P. A.
1977. Numerical studies of neutrally stratified planetary boundary-layer flow above gentle topography. Boundary-Layer Meteorol. 12(1):37-60.

A numerical model of flow above two-dimensional gentle topography is developed. Comparisons are made with surface predictions for flow over Gaussian hills. The flow at various angles above hills, valleys, and escarpments is modeled.

303. Tennekes, H.
1973. The logarithmic wind profile. J. Atmos. Sci. 30(2):234-238.

This paper explores the practical consequences of the asymptotic nature of the logarithmic wind profile in the planetary boundary layer. The value of the von Karman constant of 0.35 ± 0.02 is recommended for micrometeorological application over a smooth terrain.

304. Thom, A. S.
1968. The exchange of momentum, mass, and heat between an artificial leaf and the airflow in a wind tunnel. Q. J. Royal Meteorol. Soc. 94(399):44-55.

The coefficients C_d (momentum), C_v (mass), and C_h (heat) were determined from measurements. A generalized transfer coefficient (C_o) for mass or heat is given. C_o was shown to be proportional to (windspeed) to the minus one-half power in a regime of fully forced convection.

305. Thom, A. S.
1971. Momentum absorption by vegetation. Q. J. Royal Meteorol. Soc. 97(414):414-428.

Measurements were made in a wind tunnel of drag on elements of an artificial crop and of wind profiles above and within the crop. Values are obtained of the eddy viscosity, roughness parameters, and the von Karman constant. Wind profiles are discussed.

306. Thom, A. S.
1975. Momentum, mass, and heat exchange of plant communities. *In* Vegetation and the atmosphere, vol. 1. Principles. Chap. 3, p. 57-109. J. L. Monteith, ed. Academic Press, London, New York.

A discussion of basic principles of some meteorological processes associated with vegetation is presented. The log-wind profile is discussed along with the transfer coefficients including drag forces and eddy motion.

307. Thompson, N.
1979. Turbulence measurements above a pine forest. Boundary-Layer Meteorol. 16(3):293-310.

Measurements in neutral stability confirmed the validity of the aerodynamic method of estimating momentum fluxes above the canopy. In stable conditions, a log-linear wind profile provided a good fit to data. Spectra in unstable conditions were generally more sharply peaked than those over smoother terrain.

308. Thompson, Roger S.
1978. Note on the aerodynamic roughness length for complex terrain. J. Appl. Meteorol. 17:1402-1403.

Field data are presented that demonstrate the application of a logarithmic windspeed profile over complex terrain.

309. Thuillier, R. H., and V. O. Lappe
1964. Wind and temperature profile characteristics from observations on a 1400 ft tower. J. Appl Meteorol. 3(3):299-306.

Observed windspeed profiles are analyzed to determine the relationship to lapse rate structure. The wind profile can be divided into inversion and noninversion profiles. For adiabatic conditions, the logarithmic wind law represents the data well to a height of 300 to 400 feet. Above this height, the windspeed is nearly constant. The more stable wind profiles are represented with a power law.

310. Tomlinson, A. I.
1975. Structure of wind over New Zealand. Tech Inf. Circ. 147 (rev. of Tech. Inf. Circ. 144 by J. F. de Lisle), 24 p. New Zealand Meteorol Serv., Wellington.

The measurement and nature of the surface wind including the effect of topography and underlying surface

are discussed. The ratio of the maximum gust to the 10-minute mean wind is given for several stations. The mean hourly windspeed is represented by a Weibull distribution.

311. Turner, J. A.
1968. Standard deviation of wind direction estimated from direct observation of a sensitive wind vane. J. Appl. Meteorol. 7(4):714-715.

Wind gustiness was found by direct observation of fluctuations of a lightweight sensitive wind vane.

312. Tyson, P. D.
1968. Velocity fluctuations in the mountain wind. J. Atmos. Sci. 25(3):381-384.

The maximum turbulent energy is generated by waves of the order of 10 km in length and a period of 1 hour which fills the spectral gap between purely micrometeorological fluctuations and those of mesometeorological origin.

313. Van Der Hoven, Isaac.
1957. Power spectrum of horizontal windspeed in the frequency range from 0.0007 to 900 cycles per hour. J. Meteorol. 14(2):160-164.

There appear to be two major eddy-energy peaks in the power spectrum of horizontal wind. One peak occurs at a period of 4 days and a second peak at a period of 1 minute. Between the two peaks, a broad spectral gap is centered at a frequency ranging from 1 to 10 cycles per hour. The spectral gap seems to exist under varying terrain and synoptic conditions.

314. Van Hylckama, T. E. A.
1970. Winds over saltcedar. Agric. Meteorol. 7(3):217-233.

In 90 percent of the cases, the wind profiles above the stand can be represented by the logarithmic wind law. There was considerable turbulence within the saltcedar thicket.

315. Vukovich, Fred M., and Andrew Clayton.
1977. On a technique to determine wind statistics in remote locations. U.S. Dep. Energy, Div. Solar Energy, Final Rep. RLO-2445-781, 108 p.

A wind production technique uses historical wind data from a synoptic weather station together with a statistical prediction model to obtain data from which wind statistics in remote locations can be developed. The form of the statistical model and the parameter estimates were determined using simulations based on a hydrodynamic model. Predictions were made in and around the city of St. Louis.

316. Webb, E. K.
1970. Profile relationships: the log-linear range, and extension to strong stability. Q. J. Royal Meteorol. Soc. 96:67-90.

The diabatic profile in the surface layer was studied by applying analysis methods to data from O'Neil, U.S.A., and from Australia. It was found that the log-linear law is valid over a small range of unstable and a wide range of stable conditions.

317. Widger, William K., Jr.
1977. Estimations of windspeed frequency distributions using only the monthly average and fastest mile data. J. Appl. Meteorol. 16(3):244-247.

Average windspeed frequency distributions appear to be adequately approximated based on only the monthly average and fastest mile data. The method is based on a square-root transformation of the speeds to an approximately normal distribution.

318. Wieringa, J.
1973. Gust factors over open water and built-up country. Boundary-Layer Meteorol. 3(4):424-441.

A simple, nonspectral model for gustiness at high windspeeds in the constant shear layer is proposed and checked. The model relates gustiness to surface roughness and height above the surface for gust wavelengths of about 200 meters. Data are presented for gust factors on a lake and at the edge of a town.

319. Wieringa, J.
1976. An objective exposure correction method for average windspeeds measured at a sheltered location. Q. J. Royal Meteorol. Soc. 102(431): 241-253.

A gust factor model is used to correct for sheltering effects caused by small-scale obstacles. The actual duration of the recorded maximum gusts can be obtained from instrumentation response specifications.

320. Wilson, N. Robert, and Roger H. Shaw.
1977. A higher order closure model for canopy flow. J. Appl. Meteorol. 16(11):1197-1205.

A one-dimensional model of canopy airflow was developed with closure achieved by parameterizing higher order terms. The closure scheme relies upon a prescribed length scale. The model predicts mean wind velocity, Reynolds stress, and turbulent intensities from the soil surface to twice the canopy height.

321. Wood, D. H.
1978. Calculation of the neutral wind profile following a large step change in surface roughness. Q. J. Royal Meteorol. Soc. 104(440):383-392.

The response of a boundary layer wind profile and the surface shear to a large step change in surface roughness is predicted by three calculation methods. The first method, which assumes that local equilibrium exists everywhere, performs less well than the other methods, which employ a transport equation for the shear stress.

322. Wooldridge, Gene L., and Ronan I. Ellis.
1975. Stationarity of mesoscale airflow in mountainous terrain. J. Appl. Meteorol. 14(1):124-128.

The horizontal components of the Lagrangian velocities at levels below mountain ridges are only weakly stationary; the vertical components fit stationarity criteria better. Above ridge level, all components of the velocities exhibit reasonable stationarity in the turbulent flow.

323. World Meterological Organization.
1964. Sites for wind-power installations. Tech. Note 63, WMO-No. 156, 38 p. Geneva, Switzerland.

Several aspects of local airflow are discussed, including the sea breeze and valley wind circulations. The flow over hills and mountains is discussed in detail. The effect of air-mass stability and local insolation is also included.

324. Yerg, Donald G., and Robert E. Dohrenwend.
1979. Statistical analysis of air flow through a jack pine forest. *In* Fourteenth Conf. on Agric. and Forest Meteorol. and Fourth Conf. on

Biometeorol. [sponsored by Am. Meteorol. Soc., Minneapolis, Minn., April 2-6, 1979]. p. 110-111.

An array of Gill-type anemometers mounted 1 meter above ground was located in a jack pine forest. Results indicate that the pattern of wind fluctuations is associated with eddies generated at treetop level and carried downward.

325. Yocke, Mark A., and Mei-Kao Liu.
1977. The development of a three-dimensional wind model for complex terrain. *In* Joint Conf. on Applications of Air Pollution Meteorol [sponsored by Am. Meteorol. Soc. and the Air Pollution Control Assoc., Salt Lake City, Utah, Nov. 29-Dec. 2, 1977]. p. 209-220.

A multilayer, three-dimensional wind model, based upon mass continuity, was developed for predicting wind flow in rugged terrain. For each layer, a Poisson equation is written with wind convergence as a forcing function. Wind data from Arizona were used to test the model.

326. Yoshino, Masatoshi M.
1975. Climate in a small area. 549 p. Univ. Tokyo Press.

Local meteorology is dealt with, including wind in mountainous and forest areas. The influence of topography and temperature on local weather is discussed. Some geomorphological effects due to the influence of local climatology are described.

SUBJECT INDEX

AUTHOR INDEX

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Baughman, Robert G., compiler.
1981. An annotated bibliography of wind velocity literature relating to forest fire behavior studies. USDA For. Serv. Gen. Tech. Rep. INT-119, 28 p. Intermt. For. and Range Exp. Stn., Ogden, Utah 84401.

Lists and annotates 326 references on wind velocity. Most references relate to wind acting within the local scale of forest fires. Citations are cross-referenced by subject and author.

KEYWORDS: wind velocity, annotated bibliography, wind influence on fire, forest protection

The Intermountain Station, headquartered in Ogden, Utah, is one of eight regional experiment stations charged with providing scientific knowledge to help resource managers meet human needs and protect forest and range ecosystems.

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Forest Service

**Intermountain
Forest and Range
Experiment Station**

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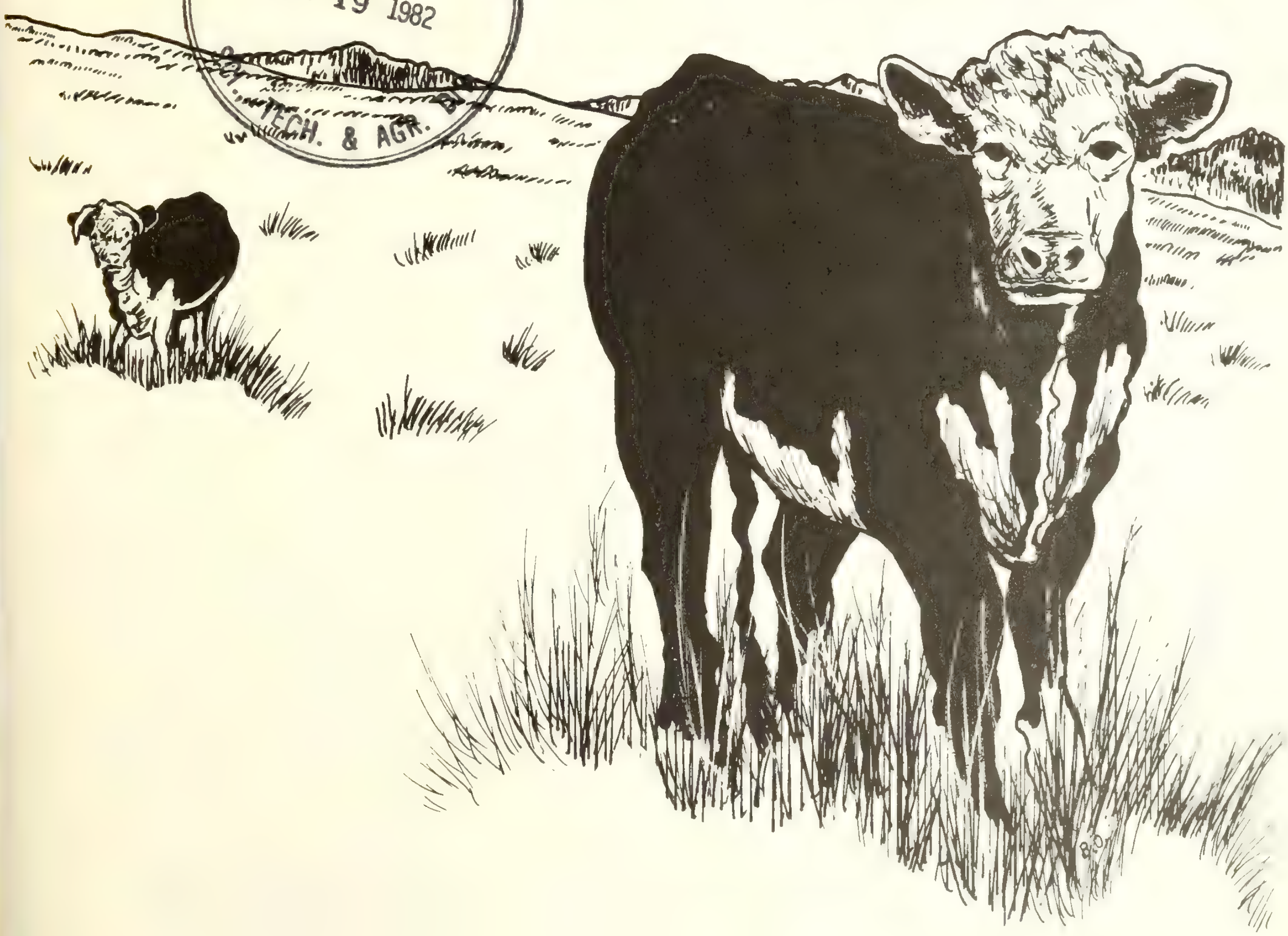
SEEDING AND FERTILIZING TO IMPROVE HIGH-ELEVATION RANGELANDS

William A. Laycock



THE AUTHOR

WILLIAM A. LAYCOCK is currently a range scientist and research leader of the Forage and Range Unit of USDA, ARS in Fort Collins, Colo. From 1961 to 1974 he was project leader in charge of high-elevation range management research for the Intermountain Forest and Range Experiment Station at Provo and Logan, Utah, and this publication is related to that assignment. He earned B.S. and M.S. degrees in range management from the University of Wyoming and a Ph.D. in plant ecology from Rutgers University.

RESEARCH SUMMARY

Seeding and fertilizing are two tools available to range managers to increase productivity on rangelands. Even though some of the earliest range management research in the United States was conducted on high-elevation rangelands, relatively little range research is now being conducted on these areas. The advent of strip mining and other activities which drastically disturb rangelands has revived interest in seeding and fertilizer research. This paper summarizes the available literature on seeding and fertilizing high-elevation rangelands to assist those now charged with revegetating or increasing productivity on such areas and also as an aid to further research.

CONTENTS

Cover caption:
Cattle on a high-elevation big sagebrush site in northeastern Utah that was plowed and seeded to a mixture of crested wheatgrass and smooth brome. Grass production on the seeded area averaged 1 500 to 1 700 kg/ha. Total grass production in the native sagebrush stand was only 450 to 500 kg/ha.

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INTRODUCTION

Seeding and fertilizing are two of the tools available to range managers to increase productivity of rangelands. Even though some of the earliest range management research in the United States was conducted on high-elevation rangelands (for example, Cotton 1905, 1908; Griffiths 1907; Sampson 1913, 1921), relatively little range research is now being conducted on these mountain areas.

The advent of strip mining and other activities which drastically disturb rangelands has revived interest in seeding and fertilizer research. Much of the more recent research, however, is being done at lower elevations and has ignored the earlier research. Many recent studies have examined methods of planting, species adaptability, fertilizing, and similar areas which duplicate earlier research. The objective of this paper is to summarize the available literature on seeding and fertilizing high-elevation rangelands in the western United States and Canada as an aid to those now charged with revegetating or increasing productivity of such areas and to further research. The lower elevation and precipitation limits of the vegetation types included are difficult to define but, in general, are those of the lower limits of the ponderosa pine type. Other vegetation types include openings or burns in higher elevation forest communities, open grasslands dominated by species of fescue (*Festuca* spp.), aspen, "mountain meadows," and alpine. Data from vegetation types or similar types in other parts of the world are included when appropriate to make comparisons or to illustrate specific points.

SEEDING

Even before the turn of the century, the problems on overgrazed mountain rangelands were beginning to be recognized. In 1897, the U.S. Department of Agriculture conducted experiments in the Big Horn Mountains of Wyoming which demonstrated that timothy[1] could be successfully seeded at an elevation of 7,000 feet (2 130 m) (Griffiths 1907). Experiments were started in 1901 on Rattlesnake Mountain near Prosser, Wash., and, in 1902, at the Wenatchee Mountain Station to determine what species of grasses could be established on the mountain range areas (Cotton 1905, 1908).

Sampson recognized that natural succession might not accomplish rehabilitation of overgrazed mountain rangelands quickly enough and began experiments in 1907 in Oregon to determine which grass species were best adapted, what time of year was best for seeding, and what cultural methods should be used (Sampson 1913). In 1912, he established two experimental areas at an elevation of almost 10,000 feet (3 050 m) on what is now the Great Basin Experimental Range of the Forest Service in central Utah on which he planted timothy, Kentucky bluegrass, orchardgrass, and smooth brome (Keck 1972). Many other trials followed as he continued his work to find species adapted to the harsh climate of high-elevation areas (Sampson 1921, 1923). Other early work in Utah showed that the abundance and character of grasses and forbs on high mountain watersheds could mean the difference between normal streamflow of clear, usable water and abnormal, disastrous mudrock floods (Reynolds 1911). Since that time, many experimental plantings have been made and numerous publications have been issued recommending such items as species, seeding methods, and time of seeding for various regions, elevations, and range types in the western United States. Those dealing with high-elevation rangelands are summarized in this paper.

[1]Scientific names of most species are listed in the appendix. Scientific names of those species not in the table are included where appropriate

Reasons for Seeding

Seeding on high-elevation rangelands generally is done to increase production of species palatable to livestock or wildlife, or to maintain or improve watershed stability. Other reasons for seeding include: replacement of weedy or low-producing species with better species; extending the period of green herbage availability; increasing the nutritive content of herbage; and providing temporary protective watershed cover for timberland disturbed by fire or logging, or altered by reshaping for use as ski slopes.

Improvement of depleted rangelands by rest, deferment, control of undesirable plants, or other management techniques should be attempted when enough desirable native species are present. The harsh climate, short growing season, and lack of seed source of desirable species on many depleted high-elevation sites often make natural revegetation very slow, however. Artificial introduction by seeding of desirable species often is the only way to speed up the healing process. Where brush or weed species have become dominant on the area, control measures usually are necessary before forage production can be increased by managing the native stand or by seeding.

Suitability of the site chosen to increase production sufficiently after seeding to warrant the investment is another factor in the decision to seed or not. Seeding is expensive and costs are rising rapidly. Methods of calculating seeding costs and returns have been described by Lloyd and Cook (1960) and others. Full consideration must also be given to the possible beneficial or detrimental effects of seeding on wildlife habitat and the possibility of erosion in case of seeding failure or runoff caused by high-intensity storms before plants become established.

A working group has been formed in Colorado dealing with the subject of revegetation of high-altitude disturbed lands. This group has sponsored publication of a bibliography pertinent to disturbance of alpine and subalpine lands in the southern Rocky Mountain (Steen and Berg 1975) and has held three workshops on the subject (Berg and others 1974; Zuck and Brown 1976; Kenny 1978). The group has also sponsored high-elevation tours and some limited research on high-elevation plant materials development (Kenny and Cuany 1978).

SEEDING TO INCREASE PRODUCTION

On many depleted high-elevation sites, seeding with high yielding and adapted species can greatly increase production of palatable herbage. Sites selected for seeding should offer a good possibility for success and the species planted must be matched to the soil, site, climate, and type of animal that will graze the area. Only a small portion o the seeding literature presents comparative forage pro-duction data on seeded and unseeded areas. Table 1 sum-marizes some representative figures on peak aboveground standing crop of grass on comparable seeded and un-seeded areas. Seeded areas generally produced 2 to 1 times as much grass as comparable unseeded areas.

Table 1.--Peak aboveground standing crop of grasses on some representative seeded and unseeded high-elevation rangeland areas

Location	Type high-elevation rangeland	Yield of grasses (air dry): Unseeded control		Seeded: 1-3 years		Seeded: ≥ 4 years	
		Lb/acre	*Kg/ha*	*Lb/acre*	*Kg/ha*	*Lb/acre*	*Kg/ha*
Utah (Orr 1957)	Subalpine grassland	340-746	381-836	2,097-4,552	2 350 5 103	--	--
Northeastern Utah (Laycock and Conrad 1981)	High-elevation sagebrush	487-750	546-841	--	--	1,338-1,579	1 500-1 770
Montana (Gomm 1962)	Subalpine grassland	7-97	8-109	68-599	76-671	998-1,319	1 119-1 479
Montana (Gomm 1974)	Openings in lodgepole pine	530-621	594-696	1,113-2,000	1 248-2 242	1,600	1 794
Colorado (Doran 1951)	Openings in aspen	120	135	600-1,200	673-1 345	--	--
Colorado (Hull and Johnson 1955)	Ponderosa pine	469	526	827-1,697	927-1 902	--	--
Northern New Mexico (Lavin and Springfield 1955)	Ponderosa pine	50-200	56-224	1,860	2 085	--	--
Eastern Oregon and Washington	Ponderosa pine	N.A.[1]		750-1,600	841-1 794	--	--
(Rummell and Holscher 1955)	Burns in subalpine forest	N.A.		642-977	720-1 095	--	--
Washington (Smith 1963)	Green fescue	N.A.		690-3,200	773-3 587	860-4,755	964-5 330
East slope Sierra and southern Cascades (Cornelius and Talbot 1955)	Mountain meadows	166-617	186-692	998-4,070	1 119-4 562	--	--

[1]N.A. = data on unseeded area not available

Peak aboveground standing crop has been the standard method of estimating production on rangelands. Such estimates are lower than, but can be correlated with, total aboveground net production (Kelly and others 1975; Singh and others 1975). Pieper and others (1974) have shown that peak herbage weight lasts only a short time and that the amount of herbage available for grazing animals for most of the grazing season is considerably less than that present at the peak.

SEEDING TO EXTEND THE GRAZING SEASON

Because many introduced cool-season grasses start growth considerably earlier in the spring than native species, seeded ranges can often be used to extend the grazing season (Currie 1969). Some introduced species also are green later in the summer or produce substantial regrowth in the fall and thus can extend the season of high-quality forage.

SEEDING TO IMPROVE SOIL AND WATERSHED STABILITY

On seedings for control of erosion, the best adapted species that will establish stands should be planted (Steen and Berg 1975). Early studies (Reynolds 1911; Forsling 1931; Bailey 1934) recognized the importance of restoring a good cover of vegetation on depleted mountain slopes to help prevent runoff and further erosion. Later studies have verified that if vigorous stands of adapted species are established, runoff and erosion can be reduced or eliminated.

On a subalpine rangeland, dominated by letterman needlegrass (*Stipa lettermanii*) on the Great Basin Experimental Range in central Utah, contour trenching and seeding in 1953 increased total ground cover and completely eliminated runoff and erosion from a depleted area (Meeuwig 1960). Species seeded were smooth brome, meadow foxtail, orchardgrass, mountain brome, and meadow brome. The seeded stand is still in excellent condition and no measurable runoff has yet occurred from the watershed (A. P. Plummer, personal communication). Grazing has not been allowed on the area since seeding.

On another watershed on the Great Basin Experimental Range, Orr (1957) found that soils on seeded and untreated areas were similar in bulk density, infiltration, runoff, and sediment production 3 years after seeding. The area was seeded with a mixture of smooth brome, tall oatgrass, meadow foxtail, reed canarygrass, orchardgrass, mountain brome, and alsike clover and was protected from grazing for 3 years. A study made after 4 additional years, during which moderate grazing had taken place (Meeuwig 1965), indicated that average protective cover by plants and litter was significantly less on the seeded plots (63 to 74 percent) than on the native plots (70 to 85 percent). The surface soil of the seeded plots had significantly greater bulk density and significantly less capillary pore space than adjacent unseeded areas, and soil eroded from infiltrometer plots was greater on the seeded plots. Meeuwig (1965) concluded that disking and seeding can be used to increase usable forage in subalpine ranges, but that areas treated should be chosen with caution because of the potentially damaging effect on infiltration and soil stability if ground cover on seeded areas is not maintained at a level sufficient to protect the soil.

Broadcast seeding of grass on burns is a standard technique for quickly restoring protective watershed cover. In the Black Hills of South Dakota, timothy, Kentucky bluegrass, and smooth brome were broadcast seeded from a helicopter after a burn in the ponderosa pine type (Orr 1970). Total ground cover of 60 percent, which reduced runoff and erosion to tolerable levels, was achieved on some sites within the first year and on the entire area within 4 years.

High elevation areas that have had severe soil disturbance from mining and similar activities pose special problems for revegetation. Most research on revegetation of badly disturbed areas is recent and thus results are rather short-term in nature. Results from short-term seeding studies can be misleading and of little value for long-term stability.

One activity which can badly disturb small areas is clearing for ski trails. In Washington, Klock (1973) recommended the following steps to insure successful revegetation of a newly cleared run:

1. Topsoil conservation.
2. Selection of adapted plant species.
3. Testing of soil fertility.
4. Correct time of seeding--usually as soon as possible.
5. Irrigation to get germination and emergence if necessary.
6. Covering seed and fertilizer with soil.
7. Mulching.
8. Control of subsequent soil disturbance.
9. Use of maintenance fertilizer.
10. Judging success no sooner than after two growing seasons.

Welin (1974) concluded that ski slopes can be successfully revegetated if not too steep.

Areas disturbed by strip mining at high elevations pose special rehabilitation problems because of the large scale of the operations and the difficulty of replacing suitable soil materials for plant growth. The recommendations outlined above for rehabilitating disturbed ski runs generally apply to revegetating spoil banks or other areas disturbed by strip mining. Especially important are conservation and replacement of topsoil material. In addition, spoil piles must be shaped and smoothed before seeding. Cook and others (1974) recommended methods, species, and special precautions necessary to revegetate mined areas in the ponderosa pine, mountain brush, aspen, and other subalpine and alpine vegetation types in the western United States.

On a copper-cobalt mine in the lodgepole pine type in Idaho, Farmer and others (1976) tested a range of potential species, soil treatments, and fertilizers to find the combination that would best provide an acceptable plant cover in the acid mine wastes. Replacement of native topsoil or subsoil and a combination of fertilization and mulch significantly increased production of all mixtures of native and introduced species. Cook and others (1970) recommended mixtures of grasses including smooth brome, pubescent wheatgrass, tall fescue, orchardgrass, and Italian ryegrass for stabilizing road cuts at high elevations in Utah where precipitation was between 20 and 40 inches (50 and 100 cm) annually. Mulches helped establish better stands of the seeded species.

Based on the few available published reports on methods and species for revegetating alpine tundra areas disturbed by mining and other factors, Brown and others (1978)

recommended planting mixtures of several species and rates of 25 to 50 pounds per acre (28 to 56 kg/ha). Their review also indicated that transplanting of alpine sod in the fall should result in successful establishment of most species. Transplanting experiments were described by Brown and Johnston (1978).

Monsen (1975) discussed recent advances in techniques for selection of plants to rehabilitate disturbed areas. He recommended planting of mixtures to accommodate variation within the disturbed areas, and use of native species where possible. The use of native versus introduced species will be discussed later.

Species for Seeding

GRASSES

The appendix summarizes the species recommended by various investigators for high-elevation rangeland vegetation types in the western United States. Only a few grass species are consistently recommended for most areas. Smooth brome was the only grass species that has been recommended as a well-adapted, and productive species on all areas, including the drier ponderosa pine type. On the moister and cooler higher elevation rangelands, such as aspen, openings or burns in high-elevation forests, and other mountain herblands, other grass species regularly recommended include: meadow foxtail, mountain brome, tall oatgrass, timothy, and orchardgrass. Mountain brome, a short-lived species (Hafenrichter and others 1968), may produce good stands for only 4 to 5 years and then be replaced by other species (Plummer and others 1955; Bleak 1968). In mountain meadows only two species, meadow foxtail and timothy, were uniformly recommended in addition to smooth brome. Species consistently recommended in the drier ponderosa pine type included crested, fairway, intermediate, beardless, and pubescent wheatgrass in addition to smooth brome. All of these wheatgrasses are well adapted to drier sites. Two wheatgrasses, intermediate and slender, can also be grown at higher elevations, however, and were recommended in some studies. Slender wheatgrass is also a short-lived species that may not persist in stands (Hafenrichter and others 1968).

Most of the species listed in the appendix are recommendations based on expected successful establishment within 2 to 4 years following seeding. Longer term results are not as plentiful. In a high elevation (9,350 ft, 2 850 m) nursery in Idaho fescue grassland area in southwestern Montana, Peterson (1953) reported that only the following grass species maintained vigorous stands over a 10-year period: smooth brome, meadow foxtail, meadow brome, Kentucky bluegrass, slender wheatgrass, and bearded wheatgrass. The first five were recommended as being the most reliable for reseeding similar subalpine areas in Montana. Sixteen species of grasses and legumes produced good stands initially, but had declined substantially by the 10th year. Fourteen additional species suffered severe kill within the first 3 years.

As many as 21 years after seeding, Hull (1974) found that smooth brome, meadow foxtail, and creeping foxtail maintained stands on mountain rangelands in southeastern Idaho, northeastern Utah, and western Wyoming. Intermediate and pubescent wheatgrasses were adapted to intermediate and lower mountain ranges. Other grasses that performed well in the long-term seedings were mountain, subalpine, and Regar brome, timothy, orchardgrass, tall oatgrass, reed canarygrass, and hard fescue (appendix). Legumes and forbs that persisted over long periods included birdsfoot trefoil, crown vetch, alfalfa, bird vetch, and horsemint. Twelve species of grasses and five species of legumes produced only fair-to-poor stands and an additional 25 species of grasses and nine species of legumes failed to produce stands. Mixtures of adapted species generally resulted in better stands than single-species seedings.

To evaluate results over a longer period of time, Hull (1973) examined stands of species seeded experimentally from 1936 to 1939 on depleted and terraced mountain rangelands in northern Utah. By 1971, only smooth brome, tall oatgrass, intermediate wheatgrass, and red fescue still formed fair-to-excellent stands. The other 33 species seeded had disappeared or formed only poor stands. The area had not been grazed by livestock since the 1930's when the rangelands were terraced and seeded to restore watershed stability.

Gomm (1974) reported results of seeding trials in various vegetation types in Montana and summarized data not published or available elsewhere. Results of individual trials are not presented here, but they included studies in alpine grassland, subalpine forest and grassland, Douglas-fir-larch forest, lodgepole pine-Douglas-fir forest and grassland, and western ponderosa pine forest and grassland areas.

Two years after seeding on a copper-cobalt mine in the lodgepole pine type in Idaho, orchardgrass and timothy produced the highest density of any species tested in mixtures of several species (Farmer and others 1976). Other introduced species that performed reasonably well in the mixtures were timothy and orchardgrass. Squirreltail (*Sitanion hystrix*) and western yarrow (*Achillea millefolium*) were the most successful native species. The wheatgrass (crested, intermediate, western, and bluebunch) produced good stands the first year after seeding, but survival the second year was poor.

Studies of direct seeding and transplanting of individual species or native sod have been conducted on alpine areas on the Beartooth Pateau in Montana disturbed by mining (Brown and Johnston 1978; Brown and others 1976; Brown and Johnston 1976). Species successfully established by either seeding or transplanting included Scribner wheatgrass (*Agropypon scribneri*), slender wheatgrass, meadow foxtail, tufted hairgrass (*Deschampsia caespitosa*), alpine timothy, alpine bluegrass (*Poa alpina*), and spike trisetum (*Triestum spicatum*). The introduced species, meadow foxtail, smooth brome, timothy, intermediate wheatgrass, tall fescue, and orchardgrass were also successfully seeded (Brown and Johnston 1976) and seed is commercially available. In a subsequent study (Brown and Johnston 1978) alpine bluegrass, alpine timothy, tufted hairgrass, and meadow foxtail were the most successful species in transplant studies, with Canada bluegrass also appearing to be adapted.

FORBS AND SHRUBS

Most of the species used to seed mountain grasslands have been grasses. Only a few forbs were reported in

lier studies (appendix 1). In 1938, 24 native species (13 os, five grasses, and six shrubs) were seeded on ex- ;ed road cuts in the subalpine and alpine areas (9,500 to 800 ft [2 900 to 3 600 m]) in Rocky Mountain National k (Harrington 1946). Six years after planting, 15 of the species were abundant enough to indicate promise for ding purposes. Arranged in descending order of rela- desirability and success, the species were: spreading den pea (*Thermopsis divaricarpa*); silky phacelia *acelia sericea*); varileaf phacelia (*Phacelia hetero- lla*); rough bent (*Agrostis scabra*); tufted hairgrass; untain brome; cow parsnip; spike trisetum; cliff jamesia *nesia americana*); alpine bluegrass; cryptantha */ptantha virgata*); western yarrow; American red rasp- y (*Rubus strigosus*); sagewort (*Artemisia norvegica saxatilis*); and whipple penstemon (*Penstemon opleanus*). Even though seeding of silky phacelia was e successful, transplanting of the same species failed.

1950, mountain brome, blue wildrye, cow parsnip, and tern coneflower (*Rudbeckia occidentalis*) were planted penings and under aspen canopy at an elevation of 0 ft (2 740 m) in central Utah (Ellison and Houston 3). Three years after planting, plots in the open were h more productive than those under the canopy. The grasses and western coneflower were productive and essful on all plots. Cow parsnip became established under the aspen canopy, indicating a strong micro- atic selection which would limit use of this species to t, cool, or shaded sites.

e practice of planting a mixture of species, including mes and other forbs, has been given increased atten- in recent years. In addition to those listed in the endix, Plummer and others (1968) listed many other s, legumes, and shrubs that are adapted to aspen and lpine ranges in Utah.

ing Methods

is publication is not intended to be a methods hand- for reseeding mountain rangelands. Some consis- /, however was found in the available literature that ated the conditions and methodology necessary for essful seeding.

G ADAPTED SPECIES

st of the introduced grasses and some of the native es recommended in the appendix are available from nercial seed sources. Where more than one variety of cies is available, the variety best suited to the condi- in the area should be used. The characteristics of the common grasses and legumes used for seeding in the c Northwest and Great Basin States are described in l Conservation Service Handbook (Hafenrichter and s 1968), in the Oregon Interagency Guide (Anderson, and elsewhere.

Soil Conservation Service has established a number nt material centers to study and develop grasses and nes for use in conservation; to determine reliable cul- and management methods; and to get proven ials into production by farmers, ranchers, and com- al growers (Hafenrichter and others 1968). The most tly established plant material center is at Meeker, (Burdick 1975). This new center is in a large area of elevation rangelands and is primarily concerned with testing adapted native species for seeding at high eleva- tions, as well as at lower areas.

Native Versus Introduced Species—Currently, there is considerable controversy over the desirability of seeding native species rather than introduced species, especially for the revegetation of areas disturbed by strip mining. Recommendations and regulations requiring use of native species apparently are based on the assumption that, because a species grew on the site before distur- bance, it would be better adapted than introduced species if it were to be put back on the site. There is little evidence to support this assumption, but there are many examples of stands of introduced species maintaining high production and site stability for long periods of time. Many of the earliest stands of crested wheatgrass planted before and during the 1930's are still intact in spite of a long history of heavy grazing. Smooth brome planted by Sampson (1913, 1921) in 1912 at about 10,000 ft (3 050 m) elevation on the Wasatch Plateau in Utah has spread far beyond the original plots and still maintains good stands.

Hull (1973) examined stands of grasses and forbs planted from 1936 to 1939 on depleted and terraced mountain rangelands in Utah. In 1971, smooth brome, tall oatgrass, and intermediate wheatgrass still formed excellent stands and had spread well beyond the area originally seeded. Red fescue still formed fair stands on favorable sites. The remainder of the 25 grass species and 12 forb species originally planted either had disappeared by 1971 or had formed only poor stands. Of the 33 seeded species which failed to produce stands, 11 were native grasses and seven were native forbs. Native grasses, forbs, shrubs, and trees had reinvaded all seeded areas by 1971. In areas where seedings had failed and native species had not reinvaded, annuals still dominated.

The long-term observations in Utah illustrate the import- ance of establishing a good stand of adapted species as rapidly as possible on disturbed areas. Frequently intro- duced species are the species most available and best suited to accomplish this. In time, native species will re- invade the seeded area on most sites and again become part of the community.

Species selected for seeding should be those best suited to the site and best fitted to the reasons for seeding. At present, introduced are the best choice in many, perhaps most situations for the following reasons:

1. Introduced species have a long history of improve- ment and selection for high productivity. Under favorable moisture conditions, well-adapted introduced species usually produce significantly more herbage than do species native to the site.
2. Cool-season, introduced grasses "green-up" con- siderably earlier than most native species, thus extending the grazing season or taking pressure off of native stands at the vulnerable early growth stage.
3. Palatability of many introduced species can be signi- ficantly greater than that of species native to a site.
4. Seed of introduced species is available commercially in quantity and generally at a lower price than seed of native species. Seed of native species is often collected near the site to be seeded at rather high costs per pound. Such seed is often of low quality.
5. Germination rates and ease of establishment tend to be greater for introduced species than for native species.

This difference is especially true when the native seed is collected locally.

6. Grazing resistance and longevity of at least some introduced species are far superior to the species native to the site. For example, crested wheatgrass and smooth brome can survive heavy use, and stands persist for many years. Some of the native species for which commercial seed is available are short lived; for example, mountain brome, slender wheatgrass, bearded wheatgrass, and blue wildrye (Hafenrichter and others 1968).

REMOVING COMPETITION

Competition for moisture from existing plants may completely prevent seedlings of seeded species from becoming established. Various ways to remove or reduce competition include burning, plowing, disking, and chemical control. In general, plowing or disking makes the best seedbed, but this is not recommended on slopes steeper than 20 percent because of the erosion hazard (Hull and others 1958). On areas where erosion is a hazard, all seedbed preparation and drilling should be done on the contour or seeding should be done in contour furrows or terraces.

PLANTING SEED

Drilling is the best method of seeding, if the ground is sufficiently smooth and rock free, because it insures covering of seed, a well-known and essential practice for successful establishment of seedings. Rate and depth of seeding can best be controlled with a drill equipped with depth bands. Many soils require culti-packing or rolling to make a firm seedbed. Drilling into very loose soil can place seed too deep for good establishment (Gomm 1962). Press wheels on the rear of a drill can pack the soil somewhat, especially on loose soils.

Broadcasting often must be used where drilling is not possible, but covering of seed by harrow, drag, or other means should follow to get a successful stand, and seeding rates must be doubled or trebled. Sampson (1913) and Forsling and Dayton (1931) described some ingenious handmade equipment and other ways to cover seed after broadcasting, including a wooden peg "A" harrow, brush drags, and trampling by sheep following seeding. Use of livestock to trample seed into the ground to insure germination has been widely recommended since that time, and may be beneficial in some situations. One element of one of the treatments in the "rest rotation" grazing system described by Hormay and Talbot (1961) is deferment of an area until seed set, then grazing heavily to insure "planting" of seed by trampling. Little experimental evidence exists, however, to verify that this is effective on native rangelands. Hyder and others (1975) reported that the treatment is not effective for establishing new plants on shortgrass plains.

Broadcasting grass seed with no followup covering generally has met with little success on rangelands in North America, even on higher elevation mountain grasslands where precipitation is greater. In Australia, factors identified as causing failure of broadcast seeding included moisture deficiency, harvesting of seed by ants, damage by soil fauna, residual herbicides in the soil, and competition from weeds (Campbell and Swain 1973). A similar study in Washington (Nelson and others 1970) determined that depredation of seed by rodents and birds and rapidly fluctuating moisture conditions that inhibited germination and restricted penetration of seedling roots were the major factors limiting success of broadcast seedings. In Washington, Goebel and Berry (1976) found that small birds selected two small-seeded grass species in preference to larger seeded wheatgrasses. Such selective depredation could result in either a poor stand or charge the intended composition of a seeded stand, especially on broadcast seedings, but it could also cause troubles in drilled areas.

Broadcasting seeds into ashes after a burn is a standard, and usually successful, technique because the seeds sink into or are otherwise covered with ashes. Best success has been achieved when seeding was done before the first rain. Seeding has been done with hand or power broadcasters or, more commonly, by airplane or helicopter. Successful seedings resulting from this technique were reported on burns in the ponderosa pine type in Oregon (Cornelius and Talbot 1955), southern Idaho (Hull and Holmgren 1964), South Dakota (Orr 1970), and Arizona (Lavin and Springfield 1955). Similar results were obtained on burns in the spruce-fir type in Colorado (Hull and others 1958) and in lodgepole pine and Douglas-fir types in Washington (Tiedemann and Klock 1973)

A highly successful technique for seeding in the aspen type is broadcasting seed just before leaf drop. The aspen leaves cover the seed and maintain moisture conditions conducive to germination. Plummer and Stewart (194-) and Plummer and others (1955) reported this technique using a variety of species (appendix). Hull and others (1958) reported improvement of deteriorated aspen stands in Colorado by broadcasting smooth brome, orchardgrass, timothy, and Kentucky bluegrass prior to leaf fall at a rate of 3 pounds per acre (3.4 kg/ha) for each species. Successful applications of this technique in aspen were also reported in southern Idaho by Hull and Holmgren (1964) and on the east slope of the Sierra Nevada and southern Cascade Mountains of California by Cornelius and Talbot (195-). McGinnies and others (1963) reported unsatisfactory stands resulting from broadcast seeding just after aspen leaf fall and they speculated that better stands would have been obtained if seeding had been done before leaf fall. Plummer and others (1955) also recommended broadcast seeding before leaf drop in oakbrush, maple, and serviceberry tall brush stands.

Because broadcasting seed had so little success except in the specialized situations described above, attempts have been made to coat seed with various materials or compress seed into earthern pellets to overcome the need for covering after broadcasting. Hull and others (1963) summarized information of 16 large-scale range pellets seedings, covering more than 18,000 acres (7 300 ha) in the western United States. Ten trials were complete failures and six gave unsatisfactory stands. The only high-elevation rangelands included in the summary were aspen, mountain brush, and ponderosa pine on the Manti-LaSal National Forest in southeastern Utah seeded with compressed earthern pellets broadcast from an airplane at a rate of 1.2 to 2.4 pounds of seed per acre (1.3 to 2.7 kg/ha). Seven years following seeding, aspen sites seeded with pellets produced 134 pounds of grass per acre (150 kg/ha) while stands seeded with unpelleted seed produced 251 pounds per acre (281 kg/ha). The success in both cases was attributed to covering of seed by leaf fall. Pelleted seed produced only 0.1 pounds of herbage per acre (0.1 kg/ha)

n the mountain brush type (Bleak and Phillips 1950). Chadwick and others (1969) reported successfully seeding pelleted alsike clover into weedy Thurber fescue grass- ands on Black Mesa in Colorado, but the clover did not persist in the stands.

In some other grassland areas of the world, broadcast seeding is routinely used as a successful improvement echnique. Good distribution and amount of rainfall undoubtedly make the technique successful, in contrast to he general failures reported in the United States. In New Zealand, improvement of high-elevation tussock grass- ands has been largely done by oversowing (broadcast seeding) with improved grasses and legumes and top dressing (fertilizing) to improve inherently infertile soils. Use of airplanes for applying seed and fertilizer on lands too steep or ground equipment started after World War II (Campbell 956).

Broadcasting grass and clover seed and fertilizer has also been successfully used to get vegetative cover on high-elevation subsoils exposed by severe erosion in New Zealand (Dunbar 1971). Soils on such areas are extremely nfertile and fertilizers used generally contain many needed race elements as well as phosphorus, nitrogen, calcium, nd sulfur. Where successful stands are established on uch areas, followup applications of fertilizer, especially uperphosphate, usually are necessary to maintain the tand.

IME OF SEEDING

Planting should be timed so that seeds will germinate and eedlings emerge at the beginning of the longest period of vorable soil moisture and temperature. Early studies by ummer and Fenley (1950) indicated that spring and early ummer were best for planting at high elevations. Later udies have indicated, however, that late-fall seedings ten produce good stands because the seed is in place to erminate early in the spring as soon as the temperature is vorable. Generally, this is earlier than seeding equipment an be used on the area in spring because of wet soils. Fall- anted seed has a longer period of favorable moisture onditions for seedling growth in the spring than seed anted in the spring. The success of fall seeding at high evations may be limited by soil characteristics. Complete ilures from fall seeding can occur on areas where soils uddle, bake hard, or form a vesicular structure (F. B. omm, personal communication).

On high-elevation rangelands in northern Utah, Hull 966) found emergence was best from seedings in eptember, October, and June, in that order. Seedings ade too early in the fall may result in germination and bsequent frost heaving or frost kill before permanent ow cover occurs. In areas with deep snow cover, soil may aw before snowmelt and some seeds germinate under ch conditions (Bleak 1959).

EPTH OF SEEDING

Seed should be placed at the proper depth for best germ- ation and emergence, and this is related to seed size and edling vigor. Planting seed too deep with a drill can result poor emergence and not planting seed deep enough, ch as in broadcasting, can leave seeds in a position icient of moisture due to surface drying.

RATE OF SEEDING

The amount of seed needed varies with species and seeding method. Heavy rates of seeding may produce thicker stands earlier and thus protect the site from erosion, but 10 or more years after planting little difference usually is observed in stands produced as a result of different rates of seeding. In Utah and Idaho, Hull (1972) recommended that at least 12 pounds per acre (13.5 kg/ha) of pure live seed be used at high elevations in order to get a good stand within a reasonable amount of time. Cook and others (1974) recommended 7 pounds per acre (7.8 kg/ha) of pure live seed of crested wheatgrass on foothill areas drilled and at least 14 pounds per acre (15.7 kg/ha) of pure live seed when broadcast. Other investigators have used as much as 100 pounds per acre (112 kg/ha) on alpine sites using locally collected seed which had very low germinability (Brown and others 1978).

ROW SPACING

Drill row spacings usually have ranged between 6 and 24 inches (15 and 60 cm). Less seed usually is required for rows spaced further apart, but more years are required to obtain a closed stand. Close spacing may help prevent erosion and inhibit invasion by undesirable plants in the early years after seeding. Hull (1972) found little difference in herbage production from seed placed at 6- and 12-inch (15- and 30-cm) row spacings in high elevation plantings in southeastern Idaho. In the ponderosa pine zone in Arizona, Reynolds and Springfield (1953) found essentially no difference in herbage production from crested wheatgrass planted at 6-, 12-, and 18-inch (15-, 30-, and 45-cm) spacings.

MULCHES

Kay (1978) summarized some of the available information on the effect of mulches on stand establishment. He concluded that seed coverage (mulching with soil) is the single most important practice. Gates (1962) studied the effects of various mulch and fertilizer treatments on establishment of grasses on high-altitude, harsh environment sites in northern Idaho. Sawdust, evergreen boughs, and asphalt emulsion did not significantly increase establishment of planted species. Native hay, held in place by chicken wire, did result in good grass establishment, apparently as much from the seeds contained in the hay as for any other reason. Gates concluded that mulch treatments do not increase seedling emergence of seeded grasses. Other studies have indicated that mulch alone had no effect on establishment, but mulch in combination with fertilizer significantly increased stand establishment and subsequent production (Farmer and others 1976; Klomp 1968).

Various mulch treatments have been successful in seeding road cuts and other harsh sites. Cook and others (1970) found that wood fiber, straw-asphalt, jute mesh, and macerated paper mulches applied on road cuts at high elevations in Utah all provided protection to the soil surface against evaporation and erosion, produced more grass seedlings, and produced a more dense herbage cover than treatments without mulches. Chopped mature "hay" from native alpine meadows in Colorado is being investigated as a combined seed source and mulch (Ron Zuck, personal communication). More study is obviously needed on this aspect of seeding high-elevation rangelands. It may be that

relatively level range sites with only moderate disturbance will not require mulching, but areas that are heavily disturbed, raw, or without soil will require mulches for plant establishment.

PROTECTION FROM ANIMALS

Protection from big game, rabbits, rodents, and other animals may also be necessary to prevent failure of the stand. Where newly planted areas are subject to damage by rabbits and rodents, poisoned hay, grain, or salt have been effective control measures. Recent bans, however, have eliminated most poisons from use and require approval of any such operation. Use of large plantings can help avoid problems from rodents and other animals.

Pocket gophers can be one of the greatest problems where high-elevation seedings are concerned. On a high-elevation range in Utah, Julander and others (1959) reported that production of grass (timothy, orchardgrass, tall oatgrass, and smooth brome) averaged 1,270 pounds per acre (1 420 kg/ha) where gophers were controlled and only 535 pounds per acre (600 kg/ha) where they were not controlled. Garrison and Moore (1956) reported similar reductions in basal diameter of crested and pubescent wheatgrasses and tall oatgrass seedings in mountain meadows in Oregon. Both burrowing and feeding activities of the gophers were thought to be responsible for the damage to the seeded grasses in both studies. McGinnies and others (1963) reported severe damage to planted smooth brome stands in western Colorado caused by gophers burrowing down the rows and destroying the plants. Gophers can be controlled by placing poisoned bait in burrows, but the restrictions mentioned above also apply. Trapping can be effective, but is expensive. Good seedbed preparation is needed to kill the forbs that are a favored food supply, thus preventing gophers from being attracted to the seeded area (Julander and others 1959; Garrison and Moore 1956). Selection of species to be planted is also important on gopher-infested rangelands. Species able to reproduce both by seed and vegetatively, such as smooth brome and meadow foxtail, should be chosen. Unless gophers can be controlled, plants with fleshy roots, such as alfalfa and clovers, should be avoided. Eliminating native fleshy-rooted forbs by spraying with 2,4-D has also been effective in reducing pocket gopher populations (Tietjen 1973).

MANAGEMENT AFTER SEEDING

Management of livestock grazing on newly seeded areas is essential. No grazing should take place until the seedlings develop enough vigor and sufficiently large root systems to prevent uprooting and other damage from grazing. Two years of protection following seeding is commonly recommended, but this varies with area and conditions. Seeding operations should be correlated with long-term range management plans for water development, grazing systems, fencing, and other management tools. Because of differences in palatability between seeded and native species, seeded areas should be large enough to prevent damage from concentrations of either big game or livestock. Ideally, seeded areas should be large enough to manage as separate units. Plummer and others (1968) recommended that areas seeded in Utah be at least 500 acres (200 ha).

Discussion

Seeding of depleted high-elevation rangelands c markedly increase herbage production and protect si from erosion. Costs are high, however, and the procedu is not without risk. Preparing a site for seeding usua involves removal of existing plant cover, which leaves soil bare and vulnerable to erosion until the seeded sta becomes established. This can be especially hazardous high-elevation areas subject to high-intensity summ storms. If enough desirable species are present in existing vegetation so that productivity and soil protecti can be improved substantially by grazing managem fertilizer, or other management tools, then seed probably should not be attempted. If the vegetation is tremely depleted, however, or if disturbance has been severe that the original vegetation is no longer present, option to seed or not to seed no longer exists and a stan the best adapted species should be planted.

In 1931, Forsling and Dayton made the following c ment about species needed for seeding western ra lands:

> Thus far, work in artificial reseeding on rangelands has been confined largely to cultivated species and a few native western range plants. There are still many undeveloped possibilities such as further trials with native range plants, the search in foreign countries for plants suited to western range conditions, and the development of more suitable forms by plant breeding and selection. The success with the few native western species tried, the successful introduction into the Unitec States of many foreign species for other purposes and breeding up of cereals and other crop plants suggest that promising results will be attained as more attention is devoted to range forage plants

Additional breeding, selection, and field testing been done on some range species by the Soil Conserv Service Plant Material Centers and others. Forsling Dayton's comments, however, are nearly as appli today as they were in 1931.

The total area of depleted high-elevation rang requiring seeding is not known. Estimates made i 1950's indicated very substantial areas in the we United States that were in depleted condition and in n seeding, include:

Intermountain area (Plummer and others 1955). .... 20 million acres (8.1 millic
Montana (Short and Woolfolk 1952) .... 3 million acres (1.2 millic
Ponderosa pine zone in Colorado (Hull and Johnson 1955) .... 500,000 acres (202 0
Summer ranges in Oregon and Washington (Rummell and Holscher 1955) .... 600,000 acres (243 0
Plateau region of northeastern California (Cornelius and Talbot 1955) .... 500,000 acres (202 0

The last three of these references refer specific high-elevation rangelands. There are, however, subs acreages of high-elevation areas included in the est from Montana and the Intermountain area. Only

fraction of the indicated area has been seeded since the 1950's, but some areas have undoubtedly been improved by better management systems.

The inventory of the nation's range resources compiled by the Forest-Range Task Force (1972) indicated that more than 72 percent of the nonforested western range area was in poor-to-fair condition, with 98 percent of the alpine zone in poor condition, 58 percent of the mountain meadows in poor-to-fair condition, and 55 percent of the mountain grasslands in poor-to-fair condition. I feel that these estimates of depleted rangelands are substantially too high for these types because of inadequate or improper condition criteria. It does appear, however, that the need for seeding large areas of high-elevation rangelands to increase productivity and soil stability still exists.

FERTILIZING

Reasons for Fertilizing

High-elevation rangelands have been fertilized mainly to increase production of palatable species for livestock. Other reasons for fertilization have been to: increase palatability, increase nutrient quality, extend the period of green growth, influence distribution of livestock, increase emergence and survival of seeded species, hasten improvement of deteriorated areas, and renovate unproductive senescent stands of seeded grasses.

Use of fertilizers on grasslands often has high appeal compared to some other methods because of the ease of application, minimal soil disturbance, immediate visual response in some cases, and generally no deferment period following application (Ryerson and Taylor 1975).

Ryerson and Taylor (1975) outlined two approaches in using fertilizers on rangeland. The first approach is the one most commonly used on high-elevation rangelands and focuses on stimulating increased production from species already present without destroying the natural multi-species complex. The second approach attempts to maximize productivity by repeated applications of fertilizer. This favors species that can best respond and survive under fertilization and, if carried on long enough, can drastically change species composition.

Retzer (1954) pointed out that plants will respond to fertilizer when the fertility status of the soil is low or unbalanced. Tests usually are needed to determine fertilizer needs, but even these will not ensure response because soil moisture and other environmental factors must not be limiting if a response to fertilizer is to occur.

Duncan and Hylton (1970) reviewed the effects of fertilizer on quality of range forage and found generally conflicting evidence because of great variability in climate, soils, growth habits, state of maturity at harvest, methods of sampling, plant parts sampled, and the descriptive units in which results were reported. They concluded that nitrogen (N) probably has improved forage quality more consistently than any other type of fertilization, resulting in increased crude protein, increased succulence, increased leaf-to-stem ratios, and extended periods of green growth.

Williams (1972) reviewed the role of fertilizers in wildlife management. He concluded that fertilizer, especially nitrogen, influences production, nutrient content, and palatability of plants consumed by wild animals, but that little was known about how such changes in the plants affect game populations.

Results of Fertilizer Trials

Results of fertilizer trials on high-elevation rangelands are summarized below. Fertilizer trials on irrigated or flooded mountain meadows have not been included.

Results from fertilizer trials on mountain rangelands have varied, ranging from no response to significant response. In studies to determine effects on production, where responses have been found, the effective fertilizer usually has been nitrogen. Pot tests of soils from 10,200 to 10,600 feet (3 110 to 3 230 m) in the Medicine Bow Mountains in southeastern Wyoming indicated that the soils tested were deficient in available phosphorus (Smith 1966). Phosphorus (P) fertilizer, however, has produced increases in few field studies, but combinations of N plus P have produced additive effects in some studies. Potassium generally is not limiting in western soils and ordinarily is not included in fertilizer trials.

Retzer (1954) studied response to fertilizer of the vegetation on seven soils from the ponderosa pine and spruce zones in Colorado. Nitrogen applied at 32.5 pounds per acre (36 kg/ha) increased herbage on soils from granitic materials for 1 to 2 years after application. No response to N fertilization was found on soils derived from basalt and andesite. Responses to P, K, and minor element fertilization were inconclusive.

On Idaho fescue ranges in the Bighorn Mountains of Wyoming, Lang (1956) found no increase in forage production following nitrogen fertilization in the form of urea at a rate of 67.5 pounds per acre (76 kg/ha). The fertilized areas, however, were used much more heavily by cattle than adjacent unfertilized areas, which were grazed only slightly (Smith and Lang 1958). In a followup fertilization study, nitrogen was applied at rates of 0, 25, 50, 75, and 100 pounds per acre (0, 28, 56, 84, and 112 kg/ha) in the form of ammonium nitrate. In the year following application, yield of grasses increased about 150 pounds per acre (168 kg/ha) for the 25 to 50 pounds per acre (28 to 56 kg/ha) nitrogen applications, and only slightly higher increases in yield occurred at the 75 and 100 pounds per acre (84 and 112 kg/ha) rates. Although the increase in grass production was statistically significant, it did not approach economic feasibility. Increases in forb production followed a similar pattern but on a much smaller scale. Crude protein content of Idaho fescue plants was increased by all applications of nitrogen fertilizer, but the maximum rate of increase was with the application of 25 pounds per acre (28 kg/ha) of nitrogen. At higher levels of nitrogen further increases in protein were small. In the same area, Smith and Lang (1962) reported the results of joint applications of 2,4-D and fertilizer at rates of 0, 50, 100, and 200 pounds per acre of nitrogen (0, 56, 112, and 224 kg/ha). Maximum increase in grass production was obtained with 200 pounds per acre (224 kg/ha) of nitrogen in combination with the herbicide, but the practice was not economically feasible

On Idaho fescue grasslands in northeastern Oregon, Baldwin and others (1974) found that fertilization at very high rates markedly increased forage production (table 2). In the 4 years following application of 297, 594, and 1,188 pounds (333, 666, and 1 332 kg/ha) of 27-12-0 fertilizer, the fertilized plots produced an average of 4,220 pounds per

acre (4 730 kg/ha) per year, while the unfertilized plots averaged 1,480 pounds per acre (1 660 kg/ha). The three rates of fertilizer did not differ significantly in production. All levels of fertilization increased the lengths of the green forage season by about 6 weeks, and temporarily increased nitrate nitrogen in the forage. Nitrate levels at the two highest rates of fertilization were in the toxic range for a short period of time. All rates of fertilization increased the proportion of the introduced grass, Kentucky bluegrass, in the composition. No analysis was made of the economic feasibility of this high rate of fertilization.

On green fescue (*Festuca viridula*) grassland in Washington, Smith (1963) reported that 200 pounds per acre (224 kg/ha) of ammonium sulphate applied the year 14 different grasses were seeded resulted in more grass production than on unfertilized plots the year following seeding. The amount of the increase was not quantified and no response from the fertilizer was evident 3 years after seeding. Superphosphate applied shortly after planting at the rate of 200 pounds per acre (224 kg/ha) on plots planted to various legumes had no effect on establishment or production of any species.

On a Columbia and Richardson needlegrass (*Stipa columbiana* and *S. richardsonii*) grassland site in British Columbia, nitrogen fertilization up to 100 pounds per acre (112 kg/ha) did not increase productivity significantly, but phosphorus applied at 60 pounds per acre (68 kg/ha), both alone and in combination with nitrogen, did increase productivity slightly (Hubbard and Mason 1967) (table 2). These grassland areas were originally a rough fescue and beardless wheatgrass association.

On ponderosa pine-Arizona fescue range in Arizona, Lavin (1967) reported that one fall broadcast application of 33, 66, or 99 pounds per acre (37, 74, or 111 kg/ha) of nitrogen per acre increased herbage production of intermediate wheatgrass for four growing seasons. Increases the first growing season were the greatest (table 2). Production from the 99 pounds per acre (111 kg/ha) application, however, did not significantly differ from production at the 66 pounds per acre (74 kg/ha) of nitrogen in any year. Phosphorus alone, or in combination with nitrogen, did not increase production.

In the ponderosa pine zone in Colorado, McGinnies (1968) applied nitrogen at five rates up to 100 pounds per

Table 2.--Comparison of peak aboveground standing crop on fertilized and unfertilized high-elevation rangeland areas

Location	Type of high-elevation rangeland	Type	Rate		Yield of grasses years following fertilization: 1 year		2 years		3 years	
			Lb/acre	*Kg/ha*	*Lb/acre*	*Kg/ha*	*Lb/acre*	*Kg/ha*	*Lb/acre*	*Kg/ha*
Northeastern Oregon	Idaho fescue	Control	0	0	1,042	1 168	1,638	1 836	1,613	1 808
(Baldwin and others		27+12	297	333	4,667	5 232	3,965	4 445	3,192	3 578
1974)		(N+P)	594	666	4,875	5 465	5,436	6 094	2,636	2 955
		plus 4%S	1,188	1 332	2,979	3 339	5,326	5 970	2,874	3 191
British Columbia	Needlegrass (origi-	Control	0	0	656	735	455	510	1,279	1 444
(Hubbard and	nally rough fescue)	N	100	112	673	754	498	558	1,325	1 485
Mason 1967)		P_2O_5	60	68	778	872	479	537	1,546	1 733
		(N+P)	(60+60)	(68+68)	892	1 000	519	582	1,486	1 666
Northern Arizona	Ponderosa pine-	Control	0	0	887	994	972	1 090	430	482
(Lavin 1967)	Arizona fescue seeded	N	33	37	1,394	1 563	1,233	1 382	456	511
	to intermediate	N	66	74	2,025	2 270	1,493	1 674	498	558
	wheatgrass	N	99	111	2,080	2 332	1,666	1 867	510	572
Colorado	Ponderosa pine-	Control	0	0	1,044	1 170	1,124	1 260	546	612
(Currie 1976)	Arizona fescue[1]	(N+P+K)	(50+50+40)	(56+56+45)	2,110	2 365	1,628	1 825	686	769
Colorado	Ponderosa pine	Control	0	0	289	324	617	692	595	667
(McGinnies 1968)	seeded to crested	N	20	22	489	548	673	754	616	690
	wheatgrass	N	80	90	781	876	966	1 083	633	910
		N	160	180	767	860	1,103	1 236	867	972
		N	400	449	748	839	1,657	1 857	1,302	1 460
Southwestern Utah	Openings in spruce-	Control	0	0	470	527	1,212	1 358	--	--
(Bowns 1972)	fir	N	60	68	728	816	1,862	2 087	--	--
		P	60	68	628	704	1,777	1 992	--	--
		(N+P)	(60+60)	(68+68)	836	937	1,972	2 211	--	--
Northeastern Utah	Openings in spruce-	Control	0	0	5,159	5 783	5,148	5 771	--	--
(Hull 1963)	fir seeded to	N	100	112	5,483	6 146	4,867	5 456	--	--
	pubescent wheatgrass	N	200	224	4,882	5 473	4,820	5 403	--	--
		N	600	672	5,285	5 924	4,961	5 561	--	--
		P_2O_5	200	224	5,428	6 085	5,218	5 849	--	--
		(P+N)	(200+100)	(224+112)	5,487	6 151	5,171	5 797	—	--
Northern Utah	Native mountain	Control	0	0	943	1 057	--	--	--	--
(Cook 1965)	meadows	N	80	90	1,442	1 617	--	--	--	--
		P	80	90	1,092	1 224	--	--	--	--
		(N+P)	(80+80)	(90+90)	1,880	2 107	—	--	--	--

[1]Figures include both grasses and forbs.

acre (112 kg/ha) annually and biannually for 6 years to an old stand of crested wheatgrass. Unfertilized plots declined in vigor, but as little as 20 pounds per acre (22 kg/ha) applied annually appeared to prevent stand deterioration. Total average herbage yield was highest at the 60, 80, and 100 pounds per acre (68, 90, 112 kg/ha) rates. In another experiment a one-time application of N was applied at nine rates up to 400 pounds per acre (449 kg/ha). The 10 and 40 pounds per acre (11 and 45 kg/ha) rates increased herbage yield in the first year; the 60 to 200 pounds per acre (68 to 224 kg/ha) rates increased yield through the third year; and the 400 pounds per acre (449 kg/ha) rates increased yield through the fourth year. No rate had any effect by the fifth year. On depleted native range McGinnies (1962) found that N increased production of undesirable species but had no effect on desirable species.

Studies of native grasslands in the ponderosa pine type in Colorado (Currie 1976) have shown that 50 pounds per acre (56 kg/ha) of elemental material of each fertilizer (nitrogen, phosphorus, and potassium) provides excellent response and will increase total herbage yield 500 to 1,000 pounds per acre (560 to 1 200 kg/ha) the first 3 years following fertilizer application (table 2).

Improvement of production of the more desirable bunchgrasses was obtained by spraying depleted areas with 2.5 pounds per acre (2.8 kg/ha) acid equivalent of 2,4-dichlorophenoxy acetic acid to reduce production of the less desirable forbs. Application of a complete fertilizer, in combination with the herbicide treatment, enhanced growth of the residual grass plants.

Fertilization was also used on Sherman big bluegrass stands in the same area to modify the root growth of this species and reduce the ease with which this species is pulled up by grazing cattle. Nitrogen or phosphorus alone reduced the tensions required to pull the plants, but NP together made pulling more difficult than pulling of plants receiving no fertilizer treatment. Evaluation of plant root systems and top growth in glass-faced planter boxes indicated a close correlation between the total root system weight and the tension required to pull the plants (Haferkamp and Currie 1973).

On native subalpine parks at an elevation of 10,200 ft (3 110 m) in southwestern Utah, Bowns (1972) found significant increases in production for 2 years from a single application of nitrogen and phosphorus (table 2). Rates of application were 30 and 60 pounds per acre (34 and 68 kg/ha) of nitrogen and phosphorus, alone or in combination. The highest production was obtained from a combined application of 60 pounds per acre (68 kg/ha) of the two elements. The average production increase from adding 60 pounds per acre (68 kg/ha) of phosphorus to the 60 pounds per acre (68 kg/ha) of nitrogen, however, was only about 100 pounds per acre (112 kg/ha) more than the increased production from adding that amount of nitrogen alone. Crude protein content of the plants was increased only the first year following applications of all levels of nitrogen fertilizer, with or without phosphorus. Phosphorus applications had no effect on crude protein content. All levels of phosphorus fertilizer increased the phosphorus content in forage for 3 years following application. The dominant herbaceous species were bistort (*Polygonum bistortoides*), western yarrow (*Achillea lanulosa*), bluegrass (*Poa canbyi*), tufted hairgrass (*Deschampsia caespitosa*), spike trisetum (*Trisetum spicatum*), alpine timothy, and letterman needlegrass (*Stipa lettermanii*).

On native mountain meadows in northern Utah, Cook (1965) found that nitrogen and phosphorus, singly and together, applied for 3 consecutive years significantly increased herbage yield. Nitrogen alone, at 80 pounds per acre (90 kg/ha), increased forb production by 240 pounds per acre (270 kg/ha) and grass production by 500 pounds per acre (560 kg/ha) (table 2). Phosphorus alone had a smaller effect, but nitrogen and phosphorus together appeared to have an additive effect, since 80 pounds per acre (90 kg/ha) of nitrogen plus 80 pounds per acre (90 kg/ha) of phosphorus increased total yield of grass and forbs from 1,479 pounds per acre (1 658 kg/ha) to 2,245 pounds per acre (2 517 kg/ha).

On unirrigated mountain meadows in Utah seeded to smooth brome, nitrogen applied at either 40 or 80 pounds per acre (45 or 90 kg/ha) increased yield more than 1,000 pounds per acre (1 120 kg/ha) the year following application, but the increase dropped to about 100 pounds per acre (112 kg/ha) the second year (Cook 1965). Total protein content of the grass was significantly higher on the fertilized area for the first and second years following fertilization.

Cook (1965) also reported that applications of 60 pounds per acre (67 kg/ha) of nitrogen increased palatability of forage on native mountain slopes. This induced heavier grazing on these areas. He suggested that this is a way to increase use of poorly utilized areas but emphasized that fertilization had to be combined with proper moving of cattle to make best advantage of the increased palatability.

Hooper and others (1969) made a preliminary economic analysis of the use of fertilizer to improve livestock distribution on aspen and mountain sagebrush ranges in northern Utah. The fertilized areas produced 2,160 pounds of forage per acre (2 402 kg/ha) while control areas produced 1,580 pounds per acre (1 770 kg/ha). The increase in yield did not pay the cost of fertilizing. Increased utilization, however, for 2 years following fertilization, increased grazing capacity enough to cover the costs. They cautioned that fertilizer should not be placed where animals normally congregate and that areas should be sufficiently large (at least 30 acres [12 ha]) so that excessive use would not occur.

On high elevation mountain grassland parks in Montana, Gomm (1962) found that 100 and 200 pounds per acre (112 and 224 kg/ha) of nitrogen or phosphorus alone, and in combination, applied at the time of seeding had no effect upon the number of seedlings of meadow foxtail, smooth brome, and Kentucky bluegrass established. Heavy grazing by sheep destroyed the stands and prevented further evaluation. Annual precipitation in the area was about 25 inches (64 mm). In a greenhouse study, using soils from the same areas, the same rates of fertilizer increased growth of grass after the third leaf stage. Crested wheatgrass and orchardgrass responded the most, tall fescue responded in an intermediate fashion, and timothy responded the least to fertilizer.

On disturbed sites on lodgepole pine, Douglas-fir, and subalpine fir types in Washington, ammonium phosphate sulfate fertilizer applied at a rate of 48 pounds per acre (54 kg/ha) of N and 60 pounds per acre (67 kg/ha) of P increased emergence, establishment, and ground cover in

individual grass species trials. Mixtures of species, however, did not form satisfactory stands either with or without fertilizer (Klock and others 1975).

On high elevation stands of pubescent wheatgrass seeded into openings in a spruce-fir stand in northern Utah (elevation 7,700 ft, [2 350 m]), Hull (1963) found no significant increase in grass production 5 years after seeding. Twenty, forty, and sixty pounds per acre (22, 45, and 68 kg/ha) of nitrogen (ammonium nitrate) and 200 pounds per acre (224 kg/ha) of phosphorus (treble superphosphate) were applied singly or in combination the previous spring or fall. Annual precipitation in the area was approximately 32 inches (81 cm). In the same general area, but at 8,400 feet (2 560 m) elevation, fertilizer applied at the time of seeding did not significantly affect the number of seedlings of intermediate wheatgrass, slender wheatgrass, pubescent wheatgrass, smooth brome, or hard fescue emerging or plants surviving after 3 years.

In the same area, Hull (1963) also reported that nitrogen and phosphorus fertilizer applied both in the spring and fall 3 years after seeding timothy, meadow foxtail, smooth brome, tall oatgrass, orchardgrass, and intermediate wheatgrass had no significant effect on herbage production (table 2). Nitrogen applied at 100, 200, and 600 pounds per acre (112, 225, and 672 kg/ha) in October was not found in the soil as nitrate nitrogen the following year. Nitrogen applied in May was found only in the top 6 in (15 cm) of soil in August. Hull concluded that the nitrogen was probably leached by the 30 to 40 in (76 to 102 mm) of water from late-fall rain and snowmelt. Complete leaching, however, did not take place because all levels of nitrogen fertilizer increased protein content of the grass.

Berg and Barrau (1978) reported that addition of 60 pounds (68 kg/ha) of N annually for 2, 3 or 4 years substantially increased the ground cover of seeded grasses on exposed glacial till at high-elevation sites in Colorado.

Use of Legumes to Increase Nitrogen in Soils

It is generally assumed that legumes increase nitrogen content of the soil and increase herbage production, but few definitive studies have been carried out on rangeland areas. On high-elevation wet meadows seeded to smooth brome, orchardgrass, meadow foxtail, timothy, reed canarygrass, and intermediate wheatgrass, presence of alsike clover was almost as effective as 200 pounds per acre (225 kg/ha) of nitrogen for increasing yield. The clover, however, did not persist in the stands after 2 years (Grable and others 1965).

Cook and others (1970) reported that red and alsike clovers and vetches (*Vicia* spp.) helped maintain vigor of grasses seeded on high-elevation road cuts in Utah because of the added nitrogen.

Bleak (1968) tested nine different legumes in mixtures with various grasses on mountain rangelands in central Utah. Cicer milkvetch and three varieties of alfalfa (A-169, Ladak, and Rhizoma) did well and increased total production of the stand an average of 144 pounds per acre (161 kg/ha). Compared with pure grass stands, flat peavine (*Lathyrus sylvestris*), perennial milkvetch, sickle milkvetch (*Astragalus falcatus*), birdsfoot trefoil, and Siberian alfalfa (*Medicago falcata*) either died out completely or formed poor stands. Smith (1963) reported good stands of birdsfoot trefoil, flat peavine, and perennial milkvetch 3 years after planting on green fescue grasslands in Washingto In the same study, sainfoin (*Onobrychis viciaefolia* Nomad, Ladak, and Sevelra alfalfas, and cicer milkvetc failed to establish stands.

Heinrichs (1975) stated that legumes can play an in portant role in increasing production of rangelands North America. However, much research is needed breeding, selection, and management. Legumes plante with grasses on mountain rangelands often have not pe sisted in the stands because of selective grazing and f other reasons.

In Colorado, cicer milkvetch was the only introduce legume to maintain stands after 10 years at 11,000 (3 350 m). At 9,000 to 10,000 ft (2 740 to 3 050 m), alfalfa ar alsike clover established well and made good growth (Be and Barrau 1978).

Use of Manure as Fertilizer

No studies were found in which barnyard manure h been used as fertilizer on high-elevation rangelanc Manure has been used successfully, however, to increa yields of grasses on other grassland types. On shortgra prairie in Canada, plots receiving one application of 12 to per acre (27 t/ha) of manure still produced more than twi as much forage as did untreated areas 11 years aft application (Clarke and others 1943). Similar results we reported in the northern Great Plains (Heady 1952; Lod 1959; and Smoliak 1965) and on shortgrass plains Colorado (Klipple and Retzer 1959). Research is needed this method of improving mountain grasslands.

Discussion

It is apparent that fertilization of high-elevation rang lands, especially with nitrogen, can result in increased pr duction; but conditions necessary for success are not w understood or consistent. Even when success is achieve the economic feasibility is often questionable or negati Increases in palatability, higher protein content, change species composition, and longer season of green grow however, often are results of fertilization that are not tak into account in an economic analysis.

Cook (1965) concluded that herbage on most range s will respond to nitrogen fertilization. He noted, howev that before extensive areas are treated on a practical sca tests should be made on small plots to see if the benef received will justify the cost. Schlatterer (1974) was le enthusiastic. "The high cost of fertilizer and applicati the lack of consistent year-to-year production increas and the lack of consistent carryover of production creases from one year to the next over an extended peri on grazed sites, raise a question as to the econor practicability of using nitrogen fertilizer to increase p duction on rangelands in the Intermountain Regio" Rather large increases in the cost of fertilizer in the p t several years perhaps make this observation even m e meaningful. Gomm (1962) concluded that "More basic formation on the rates of application of fertilizer is need to determine the effectiveness of fertilizer for aid g establishment of seeded grasses on severely deple d rangelands." This need for further research is still true b h for fertilizer used to help establishment of seedings and r fertilizer used to increase production.

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APPENDIX

Species Recommended for Planting on Mountain Grasslands and Other High-Elevation Rangelands

Pages 18 and 19

Appendix 1.--Species recommended for planting on mountain grasslands and other high elevation rangelands

SPECIES¹	FESCUE GRASSLANDS		OPENINGS OR BURNS IN HIGH ELEVATION FORESTS, MOUNTAIN HERBLANDS											MOUNTAIN MEADOWS					ASPEN						PONDEROSA PINE					
			Forsling and Dayton 1931																											
	Thurber fescue in Colorado (McGinnies, and others 1963)	Green fescue in Washington (Smith 1963)	Inland mountains - medium to high elevation below timberline	Inland mountains - near timberline	West coastal slope - mountains	Colorado (Hull, Hervey, Doran and McGinnies 1958)	Utah (Plummer, Christensen, and Monsen 1968)	Southern Idaho (Hull and Holmgren 1964)	Montana (Short and Woolfolk 1952)	Utah, Nevada, So. Idaho & Western Wyoming (Plummer and others 1955)	Idaho, Utah, and Wyoming (Hull 1974)	Eastern Oregon and Washington (Rummell and Holscher 1955)	East slope Sierra and Southern Cascades (Cornelius and Talbot 1955)	Utah (Plummer, Christensen, and Monsen 1968)	Southern Idaho (Hull and Holmgren 1964)	Montana (Gomm 1962)	Eastern Oregon and Washington (Rummell and Holscher 1955)	East slope Sierra Nevada and South Cascades (Cornelius and Talbot 1955)	Colorado (Hull, Hervey, Doran, and McGinnies 1958)	Utah (Plummer, Christensen, and Monsen 1968)	Southern Idaho (Hull and Holmgren 1964)	Utah, Nevada, South. Idaho and Western Wyoming (Plummer et al. 1955)	Intermountain Region (Plummer and Stewart 1944)	East slope Sierra Nevada and South Cascades (Cornelius and Talbot 1955)	Colorado (Hull and Johnson 1955)	Colorado (Hull, Hervey, Doran and McGinnies 1958)	Colorado (McGinnies, et al. 1963)	Southern Idaho (Hull and Holmgren 1964)	Eastern Oregon and Washington (Rummell and Holscher 1955)	East slope Sierra Nevada and South Cascades (Cornelius and Talbot 1955)
GRASSES																														
Agrostis alba (red top)	-	-	X	X	X	-	-	-	-	-	-	-	-	X	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-
Agropyron cristatum (fairway wheatgrass)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	X	X	X	-	X
Agropyron dasystachyum (thickspike wheatgrass)	-	-	X	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Agropyron desertorum (crested wheatgrass)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	X	X	X	X	X
Agropyron inerme (beardless wheatgrass)	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	X	X	-	X	-
Agropyron intermedium (intermediate wheatgrass)	X	X	-	-	-	X	X	X	X	-	X	-	-	-	X	-	X	-	-	X	X	X	-	-	X	X	X	X	X	X
Agropyron repens (quackgrass)	X	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Agropyron smithii (western wheatgrass)	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	X	X	-	-	-
Agropyron spicatum (bluebunch wheatgrass)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-	X	X	-	-
Agropyron subsecundum (bearded wheatgrass)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	X
Agropyron trachycaulum (slender wheatgrass)	X	X	X	X	-	-	-	X	-	-	-	-	-	-	-	X	-	-	-	-	-	-	X	X	X	-	X	X	-	-
Agropyron tricophorum (pubescent wheatgrass)	-	X	-	-	-	-	-	X	X	-	X	X	-	-	-	-	-	-	-	-	-	-	-	-	X	-	X	X	X	-
Alopecurus arundinaceus (creeping foxtail)	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Alopecurus pratensis (meadow foxtail)	X	-	-	-	-	X	X	X	-	X	X	-	-	X	X	X	X	X	-	X	X	X	-	-	-	-	-	-	-	-
Arrhenatherum elatius (tall oatgrass)	X	-	-	-	-	-	X	X	X	X	X	-	-	-	-	-	-	-	-	X	X	X	X	X	-	-	-	X	X	-
Bromus biebersteinii (Regar brome)	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Bromus carinatus (mountain brome)	X	-	X	X	-	-	X	X	X	X	X	X	-	-	-	X	-	-	-	X	-	X	X	X	X	-	-	-	-	X
Bromus erectus (meadow brome)	-	X	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	X	-	-	X	-	-
Bromus inermis (smooth brome)	X	-	X	X	-	X	X	X	X	X	X	-	-	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Bromus tomentellus (subalpine brome)	-	-	-	-	-	-	X	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dactylis glomerata (orchardgrass)	X	X	X	-	X	-	X	X	X	X	X	X	-	-	-	X	-	-	X	X	X	X	X	X	-	-	-	X	X	-
Elymus glaucus (blue wildrye)	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-	X	-	-	-	-	-
Elymus junceus (Russian wildrye)	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	X	X	-	-	-
Festuca arizonica (Arizona fescue)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	X	X	-	-	-
Festuca arundinacea (tall fescue)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	X	-	-	-	-	-	-	-	-	-	-	-	-
Festuca elatior (meadow fescue)	-	-	X	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Festuca idahoensis (Idaho fescue)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-
Festuca ovina (sheep fescue)	X	-	X	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-	X	-	-	-
Festuca ovina var. duriuscula (hard fescue)	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-	X	-
Festuca rubra (red fescue)	X	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Festuca rubra var. commutata (Chewings fescue)	X	-	-	-	-	-	-	X	-	-	-	-	X	-	X	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-
Festuca thurberi (Thurber fescue)	X	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Lolium multiflorum (Italian ryegrass)	-	-	X	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Muhlenbergia montana (mountain muhley)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-
Phalaris arundinacea (reed canarygrass)	X	-	-	-	-	X	X	-	-	X	X	-	-	X	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-
Phleum pratense (timothy)	X	X	X	-	X	X	-	X	X	X	X	X	-	X	X	-	X	X	X	-	X	X	X	X	-	-	-	X	X	X
Poa ampla (big bluegrass)	-	X	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-	X	-	-	-
Poa bulbosa (bulbous bluegrass)	-	-	-	-	X	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Poa compressa (Canada bluegrass)	-	-	X	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Poa pratensis (Kentucky bluegrass)	X	-	X	X	-	X	-	-	-	-	-	-	-	-	-	X	-	-	X	X	-	-	-	-	-	X	X	-	-	-

FORBS																														
Agastache urticifolia (horsemint)	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Astragalus cicer (cicer milkvetch)	-	-	-	-	-	-	X	-	-	X	-	-	-	-	-	-	-	-	-	X	-	X	-	-	-	-	-	-	-	-
Astragalus falcatus (chickpea milkvetch)	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-
Coronilla varia (crownvetch)	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Heracleum lanatum (common cowparsnip)	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-
Lotus corniculatus (birdsfoot trefoil)	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Lupinus alpestris (mountain lupine)	-	-	-	-	-	-	X	-	-	X	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-
Lupinus sericeus (silky lupine)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-
Medicago hispida (burclover)	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Medicago lupulina (black medic)	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Medicago sativa (alfalfa)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	X	X	-	-
Medicago sativa (alfalfa) Ladak	-	-	-	-	-	-	X	-	-	-	X	-	-	-	-	-	X	-	-	X	-	X	-	-	-	-	-	-	X	-
Medicago sativa (alfalfa) Nomad	-	-	-	-	-	-	-	-	-	-	X	X	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	X	-
Melilotus officinale (yellow sweetclover)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-
Osmorhiza occidentalis (sweet anise)	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-
Sidalcea oregana (Oregon checkermallow)	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Trifolium fragiferum (Strawberry clover)	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Trifolium hybridum (alsike clover)	-	-	X	-	-	-	-	-	-	X	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Trifolium pratense (red clover)	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Trifolium repens (white clover)	-	-	X	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Vicia cracca (bird vetch)	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Vicia tenuifolia (perennial vetch)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-
Viguiera multiflora (showy goldeneye)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-
SHRUBS																														
Chrysothamnus nauseosus (rubber rabbitbrush)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-
Chrysothamnus viscidiflorus (yellowbrush)	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Purshia tridentata (antelope bitterbrush)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-
Symphoricarpos oreophilus (mountain snowberry)	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-

[1]Nomenclature follows Plummer and others (1977)

Laycock, William A.
1982. Seeding and fertilizing to improve high-elevation rangelands. USDA For. Serv. Gen. Tech. Rep. INT-120, 19 p. Intermt. For. and Range Exp. Stn., Ogden, Utah 84401.

This paper summarizes the available literature on seeding and fertilizing high-elevation rangelands to assist those now charged with revegetating or increasing productivity on such areas and also as an aid to further research.

KEYWORDS: seeding, fertilizing, range improvement, high elevation, productivity,

The Intermountain Station, headquartered in Ogden, Utah, is one of eight regional experiment stations charged with providing scientific knowledge to help resource managers meet human needs and protect forest and range ecosystems.

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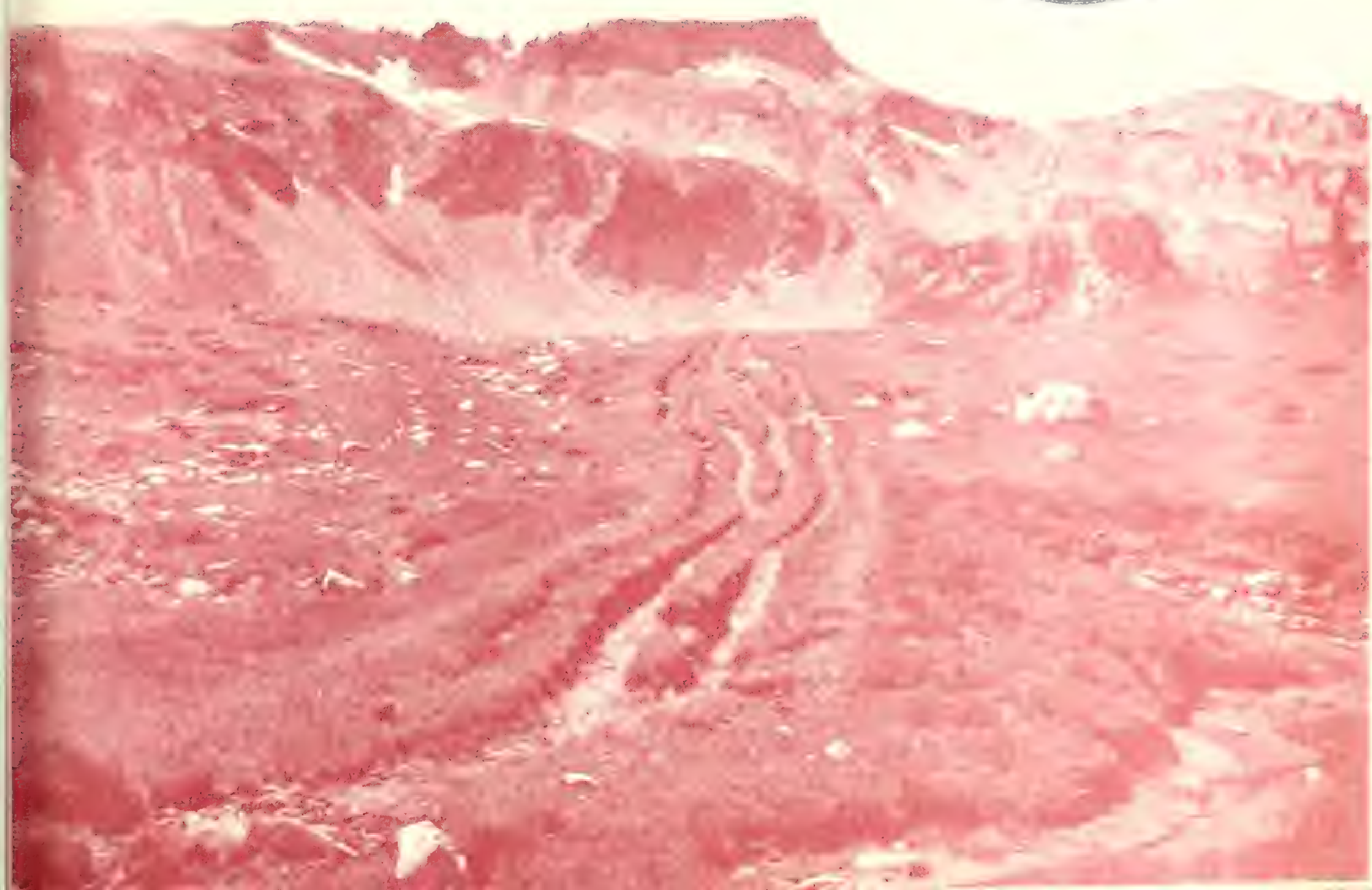
Impacts of Backcountry Recreation: Site Management and Rehabilitation — An Annotated Bibliography

David N. Cole and Edward G. S. Schreiner COMPILERS



THE AUTHORS

DAVID N. COLE is a research ecologist with the Intermountain Station's Wilderness Management research work unit at the Forestry Sciences Laboratory in Missoula, Mont. He is on intergovernmental loan from the Geography Department, University of Oregon, Eugene. Dr. Cole received his B.A. degree in geography from the University of California, Berkeley, in 1972, and his Ph.D., also in geography, from the University of Oregon in 1977.

EDWARD G. S. SCHREINER is a biological technician at Olympic National Park, Port Angeles, Wash. He received his B.S. degree in 1971, his M.S. in 1974, and is currently a Ph.D. candidate in forestry at the University of Washington, Seattle.

RESEARCH SUMMARY

Management of wilderness and backcountry areas will profit from an increased understanding of recreational impacts and of how to respond to these impacts. Over 300 references on recreational impacts, impact management, and rehabilitation of impacted sites have been annotated in this bibliography. References have been indexed by location, subject, and plant species used for rehabilitation.

ACKNOWLEDGMENTS

We are indebted to numerous people for helping us with this bibliography. In particular, we would like to thank the following for help with compilation and valuable technical assistance: J. K. Agee, J. Aho, J. Dalle-Molle, J. Kailin, J. N. Long, J. Miller, M. Miller, B. Moorhead, P. R. Saunders, R. L. Scott, and L. E. Underhill.

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INTRODUCTION

Recreational use of backcountry areas has increased dramatically in recent decades. Associated with this increased use has been an increase in the severity and extent of human disturbances of these near-pristine areas. Land managers are understandably concerned about this situation because many of them have the responsibility of maintaining the quality of this recreational resource. This is particularly true for the areas in the National Wilderness Preservation System and the backcountry of National Parks where a major goal is to preserve "natural conditions."

In order to deal effectively with the problem of human disturbance in recreation and natural areas, managers need to understand recreational impacts in sufficient detail to determine how much and what kind of change is acceptable. Since very low levels of recreational use cause at least some deviation from absolutely natural conditions, the first task facing the manager is to define what Frissell and Stankey (1972) call the "limits of acceptable change," the maximum amount of deviation from natural conditions consistent with the management objectives of an area. Such decisions should take into account general management objectives, the significance of impacts both in terms of maintaining ecosystem processes and visitor satisfaction, and the practicality of confining impacts within the chosen limits. Once a decision on the limits of acceptable change has been made, the task becomes ensuring that the limits are not exceeded, and rehabilitating places where the limits have been surpassed.

Accomplishment of the above tasks requires both detailed understanding of ecological processes and their relationship to visitor use and impact, and practical methods for managing users and sites. Although a considerable body of literature on this subject does exist, there is no "cookbook" available for making decisions. Information on impact processes and management techniques is scattered in journals, theses, and unpublished reports. We believe that an interpretive bibliography on backcountry impacts, impact management, and rehabilitation would be particularly valuable at this time, even though portions of this literature appear in other bibliographies (Stankey and Lime 1973; Speight 1973; Steen and Berg 1975; Wall 1977).

Scope of the Bibilography

This bibliography is primarily concerned with recreational impacts on the soils and vegetation of backcountry areas and with how to rehabilitate sites that have received excessive impact. We have also included helpful references on backcountry management and techniques for minimizing impact. Recreational impacts on wildlife and water quality were considered to be beyond the scope of this bibliography, although the Intermountain Forest and Range Experiment Station has just completed a complementary bibliography, "Impact of backcountry recreationists on wildlife: an annotated bibliography" (Ream 1980).

Although the main concern of the bibilography is with backcountry areas, relatively few studies have been conducted in the backcountry. Consequently, we have included many studies undertaken in areas accessible by motor vehicles. Useful information can be derived from these studies, as long as differences in management objectives and type and amount of use are kept in mind. The same cautionary advice applies to our inclusion of revegetation studies on mine spoils or logging roads, where disturbance may be more extreme than that which occurs on recreation sites. The only sources that have been purposely left out are those we considered to be redundant, overly general, or not applicable. In the cases of the Rehabilitation and Related References sections, many marginally applicable references have been included.

The thoroughness of the bibliography was advanced by distributing copies of a preliminary bibliography to experts in the field, soliciting additional references. We are responsible, however, for the final selection of references and for omissions prior to October 1979. Cole has had primary responsibility for the impact and management section and Schreiner for the section on rehabilitation. In contrast to most other bibliographies, ease of access was not a significant selection criterion; many theses and unpublished documents are included because these often contain much relevant information. We were able to find copies of all references we annotated. Although we cannot provide a library loan service, all of these references are in the files of the Wilderness Management Research Unit, Intermountain Forest and Range Experiment Station, Missoula, Mont.

Organization and Content of Annotations

The contents of the bibliography are arranged in four parts: Recreational Impact, Impact Management, Rehabilitation of Impacts, and Related References. Each reference was assigned to the section we considered most applicable. If pertinent to other sections, it is identified by number at the beginning of the section and indexed under all relevant subjects. Within sections, citations are arranged alphabetically by author.

References in the Related References section do not deal directly with the subject matter of the bibliography, but contain information that may be usefully applied. For example, we have included several papers on both soil compaction of agricultural lands and seed germination of selected species. These papers are indexed under the appropriate section. A number of potentially interesting references, which were not located before October 1979, have been listed under nonannotated references. Selected references on water quality and off-road vehicle impacts have also been listed.

It was our intent to make the bibliography more than an access tool; we wanted it to report the major findings of each reference in sufficient detail so the reader might not always have to go to the reference itself. Thus, where references contained specific information related to particularly important mangement questions, we have tried to include this information. Subjects we attempted to highlight in this manner include: the ecological significance of documented impacts; the functional relationship between impacts and environmental and use characteristics; spatial and temporal patterns of impact; specific methods for minimizing impacts; and successful as well as potential methods of site rehabilitation. The choice of which results to highlight and the interpretations and evaluations of the references are based on our personal judgments.

Most of the references report the results of short-term case studies, done in one place at one time. This raises the question of how applicable the results are to other areas. We have dealt with this problem in two ways. First, we have provided a locational index, so that the reader can concentrate on references applicable to the geographic area or ecosystem type of interest. Second, we have included evaluative comments in many of the annotations in an attempt to address the general applicability and validity of the methods and results reported.

The Rehabilitation of Impacts includes a wide variety of papers from different sources. Other sources of information and assistance in rehabilitation projects may be locally available to the manager. Garden clubs, native plant societies, rock garden clubs, and local nurseries often have people with good knowledge of the local flora and specific knowledge concerning propagation of difficult species. Another source of information is the considerable body of literature on commercial reforestation techniques.

Fertilizers described in the Rehabilitation of Impacts section require some explanation. Numbers in parentheses are the standard method of listing fertilizers and refer to the percentage by weight of total nitrogen (N), available phosphorus (P_2O_5), and water soluble potassium (K_2O). Thus, 100 units (such as pounds or kilograms) of a 16-20-0 fertilizer contain 16 units of total N, 20 units of available P_2O_5, and 0 units of water soluble K_2O. Some studies refer to the number of kilograms per hectare of a specific element or compound, rather than the number of kilograms per hectare of fertilizer. In this case, any fertilizer meeting the specifics of the study could be used. Attention should be paid to the type of fertilizer used (such as urea, or ammonium phosphate). For example, some fertilizers use nitrate (NO_3) as the nitrogen component and others employ ammonium (NH_4). Exact replication of a treatment requires the same form of nitrogen as well as the same quantity.

Indexes: Key to Using the Bibliography

The index is divided into locational and subject matter indexes. The locational index is divided into a geographic index, which includes the country, State, National Park, Wilderness Area, or mountain range in which the research was conducted, and an ecosystem type index. The subject matter index is divided into recreational impact, impact management, and rehabilitation of impacts indexes. The rehabilitation of impacts index also includes a species index for persons interested in working with particular species or in finding out what has been done with species from their own area. The species index includes notations on what type of work (such as laboratory germination, or transplanting) has been done with each species and whether or not the species was introduced or native to the United States.

It is our hope that this bibliography will serve both the backcountry manager and the researcher. It should help make the manager aware of what work has been done in his area or subjects of concern. The cautionary advice and interpretations of the data should help avoid misapplication or placing too much faith in conclusions that are not supported by data. The bibliography also gives some idea of locations and subjects which need additional research. For example, by studying the index, one can see that little research has been conducted in the southwestern United States, except on the revegetation of mine spoils, and that we know little about differences in the impacts

caused by different types of use. The bibliography should, therefore, aid in the identification of research needs, as well as in facilitating the literature search of investigators.

PUBLICATIONS CITED

Frissell, S. S., and G. H. Stankey.
1972. Wilderness environmental quality: search for social and ecological harmony. *In* Proc. Soc. Am. For. p. 170-183.

Ream, C. H.
1980. Impact of backcountry recreationists on wildlife: an annotated bibliography. USDA For. Serv. Gen. Tech. Rep. INT-81, 62 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.

Speight, M. C. D.
1973. Outdoor recreation and its ecological effects: a bibliography and review. Discuss. Pap. Conserv. 4, Univ. Coll., London, 35 p.

Stankey, G. H., and D. W. Lime.
1973. Recreational carrying capacity: an annotated bibliography. USDA For. Serv. Gen. Tech. Rep. INT-3, 45 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.

Steen, O., and W. A. Berg.
1975. Bibliography pertinent to disturbance and rehabilitation of alpine and subalpine lands in the southern Rocky Mountains. Environ. Resour. Cent. Inf. Ser. 14, Colo. State Univ., Fort Collins, 104 p.

Wall, G.
1977. Impacts of outdoor recreation on the environment. Counc. Plann. Libr. Exch. Bibliogr. 1363, Monticello, Ill., 19 p.

RECREATIONAL IMPACT

(Also see reference numbers *150, 151, 153, 154, 162, 166, 172, 192, 198, 201, 260, 269, 272, and 279.*)

1. Aitchison, S. W.
1976. Campsite usage and impact. *In* An ecological survey of the riparian zone of the Colorado River between Lees Ferry and Grand Wash Cliffs. p. 155-172. S. W. Carothers and S. W. Aitchison, eds. Tech. Rep. 10, Natl. Park Serv., Grand Canyon Natl. Park, Ariz.

Amount of campsite use was compared to an index of human impact at 41 sites along the Colorado River. There was no relationship between amount of use and impact. Sensitivity of the campsite environment and the nature of camper activities were more significant determinants of impact.

2. Allcock, P. J.
1973. Treading of chalk grassland. J. Sports Turf Res. Inst. 49:21-28.

This study utilized experimental trampling, with an artificial "foot," which approximated the pressure exerted by a human. This "foot" was dropped 0, 2, 4, 6, 10, 15, and 30 times/week for 8 weeks. Percent biomass loss was significantly related to trampling intensity, but 70 to 80 percent of the maximum loss occurred with only 2 impacts/week. Although differences were not statistically significant, loss of biomass occurred more rapidly under moist conditions, bulk density increased with trampling intensity (rapidly at first and then more slowly), and this increase was more rapid under moist conditions. The variability of the results, indicated by the lack of statistical significance, appeared to result from differences in species composition and in soil texture.

3. Bates, G. H.
1935. The vegetation of footpaths, sidewalks, cart-tracks and gateways. J. Ecol. 23:470-487.

A pioneering work on trampling effects on vegetation, which examines the conspicuous vegetational gradient perpendicular to trails — from bare earth, through a short vegetation of trampling-resistant species, to natural vegetation. A discussion of the species and growth-forms which occupy these zones is provided. *Poa pratensis* is the species most indicative of heavy trampling. Treading and puddling (formation of an impermeable surficial crust when fine-textured soils are trampled when wet) are identified as the major causes of these changes in species composition and growth form. Experiments showed that increased soil compaction, by itself, was less significant. Plants sown in consolidated soil showed reduced growth, but consolidation after seedling establishment had little effect, except on shallow-rooted plants. Morphological characteristics which promote survival along paths include conduplicate stems, folded leaves, and buds located below the ground surface. This work provides a good introduction to the study of trampled vegetation.

4. Bayfield, N.
1971. Some effects of walking and skiing on vegetation at Cairngorm. *In* The scientific management of animal and plant communities for conservation. p. 469-485. E. Duffey and A. S. Watt, eds. Blackwell Sci. Publ., Oxford.

This paper reports the results of several observational and experimental studies of human impact near a ski area in Scotland. Simulated trampling of *Phleum pratense* stimulated growth at low levels of trampling, but caused extensive damage at higher levels. *Trichophorum caespitosum*, a graminoid, was found to be more tolerant of trampling than sphagnum moss, lichens, and *Calluna vulgaris* heath. More useful for techniques than applicable results.

5. Bayfield, N. G.
1973. Use and deterioration of some Scottish hill paths. J. Appl. Ecol. 10:635-644.

The relationship between deterioration of paths in Scotland and various site characteristics was studied. Path width increased with increasing path wetness, roughness, and steepness, and decreased as the surface adjacent to the path became increasingly rough. On a newly opened path, more damage occurred as hikers walked downhill as opposed to uphill. These findings have significance to designing and locating trails.

6. Bayfield, N. G., and B. S. Brookes.
1979. Effects of repeated use of an area of heather *Calluna vulgaris* (L.) Hull moor at Kindrogan, Scotland, for teaching purposes. Biol. Conserv. 16:31-41.

Trampling by botany students over an 8-year period reduced both the cover and height of *Calluna vulgaris*. In both cases, differences were greater between control and light-use (20 students/m^2/year) zones than between light- and severe-use (80 students/m^2/year) zones, however. Changes in species richness and composition were minor at all use levels.

7. Bell, K. L., and L. C. Bliss.

1973. Alpine disturbance studies: Olympic National Park, U.S.A. Biol. Conserv. 5:25-32.

This paper describes the effects of trampling and road-cut disturbance on some alpine plant communities in Olympic National Park. Experimental trampling in snowbank and stone stripe communities showed that both productivity and cover decreased with use. Although path development was inconspicuous at the lowest trampling intensity (15 passes/week for 4 weeks), this low level of use caused more than 50 percent of the total damage. The relatively moist snowbank community was damaged more rapidly, but it also recovered more rapidly. No obvious relationship existed between degree of recovery and trampling intensity. Lichens were particularly susceptible to damage. In addition, the low diversity and cover of vegetation on a 31-year-old road cut illustrates how slowly vegetation recovers in the alpine zone. The suggested implications are that use should either be restricted in number or concentrated on constructed paths.

8. Bogucki, D. J., J. L. Malanchuk, and T. E. Schenck.

1975. Impact of short-term camping on ground-level vegetation. J. Soil Water Conserv. 30:231-232.

The immediate effects of two nights of camping by 30 people were studied on a previously unused site in New York. The site was on shallow soils under an open *Pinus banksiana* (jack pine) forest. Bedrock and bare ground increased from 10 to 15 percent as a result of reduced blueberry-moss-lichen ground cover. This illustrates the significant effects of even a short stay by a large group.

9. Boomsma, J. J., and S. W. F. van der Ploeg.

1976. Effects of three-year experimental trampling on a dune valley. Part I: effects of trampling during one season. Working Pap. 68, Inst. Environ. Stud., Free Univ., Amsterdam, Neth., 34 p.

Changes in vegetation and invertebrate fauna were noted on experimentally trampled plots. Vegetation volume (plant cover times height) decreased as trampling intensity increased, but the differences between trampling treatments were less pronounced than the difference between controls and the lightest trampling treatment. The fauna became more active following trampling, but there were no pronounced changes in species density or composition. (Compare with Chappell and others [1971, reference *22*].) Water permeability of the soil decreased in proportion to the logarithm of trampling intensity. The paper contains numerous tables and ordination diagrams, but it is not possible to conclude much from the data presented.

10. Boorman, L. A., and R. M. Fuller.

1977. Studies on the impact of paths on the dune vegetation at Winterton, Norfolk, England. Biol. Conserv. 12:203-216.

An innovative study of recreational impact on dune vegetation, utilizing air photos, ground transects, and experimental trampling. The relative vulnerability of the various vegetation types was determined by the percentage of paths in each type which were worn to bare sand. This ranking is quantified by relating each type to the rough grass type, a moderately vulnerable type which was experimentally trampled. Some types were judged to be 30 to 40 times as vulnerable as others. Vegetation damage (reduction in sward height) was logarithmically related to number of tramples, with most of the damage occurring at low trampling levels. The validity of the results must be questioned due to the many assumptions made and the fact that the original relative estimates of vulnerability did not take use intensity into account. The approach is interesting, however, as is the general discussion of results.

11. Bratton, S. P., M. G. Hickler, and J. H. Graves.

1977. Trail and campground erosion survey for Great Smoky Mountains National Park. Part I. Introduction and methods. Part II. Patterns of overnight backcountry use and the condition of campsites. Part III. The condition of trails. Part IV. The description of individual trails. Manage. Rep. 16. Natl. Park Serv., Southeast Reg., 661 p.

This report describes the condition of backcountry trails and campsites in Great Smoky Mountains National Park. Inventory methods which managers of other areas might want to consider are described. Suggestions on how they could be improved are given, although there is no discussion of the limitations of the methods used. Campsites with the most intense damage were usually horse camps and creekside sites, while sites with the greatest amount of disturbed area were usually shelters, easy access points, and trail junctions. This suggests that **intensity** of damage is primarily a function of site factors and type of use, while **area** of damage is a function of number of users. Trail problems are more extensive in areas with heavy horse use, in spruce-fir forests and early successional vegetation, and on certain trail slopes and orientations. This suggests that trail problems are more a function of location, design, and type of use than amount of use. (Compare with Helgath [1975, reference *53*].) A wealth of data is presented but little interpretation is provided. The use data that are regressed against impact are for only the last 3 years. Nevertheless, this is one of the most extensive data sets collected and could provide some valuable conclusions beyond the site-specific observations provided.

12. Bratton, S. P., M. G. Hickler, and J. H. Graves.

1978. Visitor impact on backcountry campsites in the Great Smoky Mountains. Environ. Manage. 2:431-442.

This paper summarizes part of the research reported in Bratton and others (1977, reference *11*). It describes campsite conditions in relation to site factors, type of campsite, and amount of visitation. Management implications and alternatives are discussed.

13. Bratton, S. P., M. G. Hickler, and J. H. Graves.

1979. Trail erosion patterns in Great Smoky Mountains National Park. Environ. Manage. 3:431-445.

This paper summarizes part of the research reported in more detail in Bratton and others (1977, reference *11*). Trail erosion is related to forest type, geology, elevation, trail slope, section of the park, and amount of use. Water erosion is the major trail problem and may cause severe problems even on low-use trails. Trails oriented perpendicular to contours and with slopes greater than 10 degrees are consistently in poor condition.

14. Brew, N.

1976. Biological and sociological investigations of backcountry recreation: an annotated bibliography. Unpubl. rep., Natl. Park Serv., Grand Canyon Natl. Park, Ariz., 48 p.

This is a bibliography of short abstracts and 200 citations. The more important papers are also reviewed in the present effort, but we have made no effort to include sociological references.

15. Brockman, C. F.

1959. Ecological study of subalpine meadows, Paradise Valley Area, Mt. Rainier National Park, Washington. Unpubl. rep., Natl. Park Serv., Mt. Rainier Natl. Park, Wash. 83 p.

Used and unused parts of subalpine meadows in Mt. Rainier National Park are compared. The great enviornmental heterogeneity of these meadows means, however, that unused areas do not provide adequate controls and so specific results should be used cautiously. Both the desirability and the regenerative ability of these meadows were higher than expected. Species which were particularly resistant or sensitive to recreational use are noted. The study is mostly site specific in value.

16. Brockman, C. F.

1960. Ecological study of subalpine meadows, Yakima Park and Tipsoo Lake Area, Mt. Rainier National Park, Washington. Unpubl. rep., Natl. Park Serv., Mt. Rainier Natl. Park, Wash. 96 p.

Similar to Brockman (1959, reference *15*) in that a large amount of site-specific information is provided. Observations on species response to trampling may be generally useful.

17. Brockman, C. F.

1964. Investigation of damage at Tipsoo Lake and Mowich Lake, Mt. Rainier National Park, Washington. Unpubl. rep., Natl. Park Serv., Mt. Rainier Natl. Park, Wash. 72 p.

The average amount of denuded area around Tipsoo and Mowich Lakes was 10 and 24 percent respectively. Most of the devegetated area occurred on informal trails. Site-specific observations and recommendations are included.

18. Brown, J. H., Jr., S. P. Kalisz, and W. R. Wright.

1977. Effects of recreational use on forested sites. Environ. Geol. 1:425-431.

Recreational impact on the soils and vegetation of eight developed camp and picnic sites in mixed oak and white pine forests in southern Rhode Island were evaluated by comparing recreation sites with adjacent control plots. Soils on recreation sites had higher penetration resistance and bulk density and slower infiltration rates than controls. These changes were noted to a depth of 5 in (12.7 cm). On the less sandy soils, compaction resulted in less rapid soil water recharge and depletion and, therefore, less available water during the growing season. Exposed rock and bare ground increased as a result of the virtual elimination of the ground cover of tree seedlings, shrubs (Ericaceae) and herbs; grasses, lichens, and mosses increased in cover. Studies of radial and height growth of trees showed that although most trees grew normally on recreation sites, radial growth of *Pinus strobus* (white pine) and mean annual height growth of *Quercus coccinea* (scarlet oak) were reduced on recreation sites.

19. Bryan, R. B.

1977. The influence of soil properties on degradation of mountain hiking trails at Grövelsjön. Geograf. Ann. 59A(1-2):49-65.

Soil profiles were studied both on and off trails which receive estimated differences in amount of use. While the soil profiles on high-use trails were truncated more often than soils on low-use trails, particularly severe problems were associated with certain soil properties, regardless of amount of use. Trails in stone-free soils, with homogenous textures, were always deeply incised and trails in organic soils always became quagmires. Whether a certain soil property is advantageous or not depends upon many factors, however. For example, up to a certain threshold of trail degradation, an abundance of stones in the soil resists erosion; beyond this threshold, stones in the trail increase the turbulence of runoff down the trail and exacerbate the erosion problem. The discussion of these complex interactions and the detailed observations of the trail deterioration process make this a valuable reference for understanding trail impacts.

20. Buckhouse, J. C., G. B. Coltharp, and P. A. Barker.

1973. Impact of simulated recreation on soil compaction as modified by site and management techniques. Utah Acad. Sci. Proc. 50:17-24.

Describes the results of an experiment testing the effects of simulated trampling on soil compaction and vegetative growth. Control, trampled but unmanaged, and trampled and managed (fertilized and watered) plots were established in aspen and conifer forests in Utah. Trampling was simulated with a corrugated roller. After six seasons of trampling, soil penetration resistance had significantly increased in the aspen forests. There were no significant differences in amount of compaction between the two trampling treatments, but vegetative yield was greater on the managed plots. In the conifer forests, there was no significant increase in soil compaction on the trampled plots and no difference in vegetative yield between the trampling treatments.

21. Burden, R. F., and P. F. Randerson.

1972. Quantitative studies of the effects of human trampling on vegetation as an aid to the management of semi-natural areas. J. Appl. Ecol. 9:439-457.

This important paper reviews methods of studying the effects of human trampling on vegetation. It provides examples of short-term ecological changes resulting from greatly increased use and of the relationship between use and environmental conditions on sites which are presumably at equilibrium. Possible applications of various means of measuring use and statistical techniques for data analysis (correlation, ordination, and regression) are discussed. Species which were either sensitive or resistant to trampling are identified. Rosette plants increased and cushion and straggling plants decreased in response to trampling. As a group, grasses deceased at moderate trampling intensities and then increased and decreased again with further trampling. This paper is valuable as a summary of trampling research approaches and an introduction to some research techniques and results.

22. Chappell, H. G., J. F. Ainsworth, R. A. D. Cameron, and M. Redfern.

1971. The effect of trampling on a chalk grassland ecosystem. J. Appl. Ecol. 8:869-882.

Some effects of trampling on vegetation, on soil physical and chemical properties, and on soil fauna were measured in a chalk grassland in England. The amount of trampling was assessed on the basis of vegetation wear, a circular argument when subsequently relating this amount of trampling to vegetational characteristics. The discreteness of the three zones identified, however, provides some justification for this method. Plant and animal populations were reduced by trampling and species composition changed. No significant changes in soil chemical properties (pH, C/N ratio, ferrous-ferric iron ratio, and ammonium-nitrate balance) were detected, but there were significant changes in soil structure. With increased trampling,

soils were progressively compacted, in the surface 1 in (2.5 cm) only. Even more significantly, heavy trampling resulted in a serious loss of structural stability, a condition that leads to soil erosion.

23. Cole, D. N.

1977. Man's impact on wilderness vegetation: an example from Eagle Cap Wilderness, northeastern Oregon. Ph.D. diss. Univ. Oreg., Eugene. 307 p.

A survey of vegetation changes in Eagle Cap Wilderness resulting from the construction and use of trails and campsites, grazing by packstock, and fire suppression. The relative significance of each of these sources of change was evaluated, as was the relative susceptibility of different vegetation types to each source of change. In terms of areal significance, fire suppression was the most disruptive human activity in the wilderness, although recreational impacts were more intense in localized areas. Damage to vegetation along trails, in campsites, and in meadows grazed by packstock was often greater at lower elevations than in subalpine areas. This suggests that if maintenance of natural vegetation is a concern, appropriate fire management should be a top priority, and montane ecosystems should not be ignored just because impacts in the subalpine zone are often more visible. This dissertation is mostly site specific and observational in nature, but it does provide a broad overview of impact on vegetation.

24. Cole, D. N.

1978. Estimating the susceptibility of wildland vegetation to trailside alteration. J. Appl. Ecol. 15:281-286.

Vegetation change along wilderness trails can be measured by utilizing indexes of cover reduction and floristic dissimilarity. These indexes can be used to rank different vegetation types according to their susceptibility to vegetation change. In contrast to basing susceptibility estimates on changes resulting from experimental trampling, this method does not control amount of use as accurately, but it does incorporate more of the mechanisms of vegetation change (such as, changes in soil properties and changes associated with trail construction). In Eagle Cap Wilderness, Oreg., the understory vegetation of dense forests was more highly altered along trails than the understory of open forests and meadows.

25. Coombs, E. A. K.

1976. The impacts of camping on vegetation in the Bighorn Crags, Idaho Primitive Area. M.S. thesis. Univ. Idaho, Moscow. 63 p.

Ground cover conditions were measured on campsites which appeared to receive either light or heavy use. These sites were compared with adjacent control sites. As campsite use increased, bare ground increased and vegetation cover decreased, but the amount of organic litter remained constant. The number of species was abnormally high on light-use sites and low on heavy-use sites. Invader species, which contributed to the large number of species on light-use sites, were suggested as possible indicators of a deteriorating site. *Erigeron peregrinus* and *Antennaria lanata* are examples from the study area. This study is primarily site specific in value.

26. Crawford, A. K., and M. J. Liddle.

1977. The effect of trampling on neutral grassland. Biol. Conserv. 12:135-142.

Some effects of trampling on neutral (pH approximately 7.0) grassland were studied along the River Thames in England. Relative use was estimated with trampleometers (see Bayfield [1971, reference *151*]) during a study period of unspecified duration. Soil bulk density and penetration resistance increased initially with increased amounts of trampling, but remained relatively constant with additional trampling. Particularly resistant and susceptibile species are noted, but it is generally concluded that the trampling tolerance of a species cannot be divorced from the habitat in which it grows.

27. Dale, D. R.

1973. Effects of trail-use under forests in the Madison Range, Montana. M.S. thesis. Mont. State Univ., Bozeman. 96 p.

This thesis reports some of the results also presented in the more readily available article by Dale and Weaver (1974, reference *28*). It includes a stratification of trail width and trail depth measurements according to dominant overstory species, *Pinus contorta* (lodgepole pine), *Picea engelmannii-Abies lasiocarpa* (spruce-fir), and *Pinus albicaulis* (whitebark pine). The deepest trails were found in the spruce-fir forest, the most moist type, while the widest trails were found in the whitebark pine forest, the most open type. Trailside changes in the vegetation of each of these forests are also described and related to the effects of trampling and other environmental changes.

28. Dale, D., and T. Weaver.

1974. Trampling effects on vegetation of the trail corridors of north Rocky Mountain forests. J. Appl. Ecol. 11:767-772.

This paper discusses trail width and depth in relation to use and the composition of trailside vegetation in the Rocky Mountains of Montana. Trail width increased linearly with the log of user numbers but depth showed no consistent trend in relation to use. Trail widths in meadows were generally wider at high-use levels and narrower at low-use levels than trails in forests. Trails used by horses and hikers, as opposed to just hikers, were deeper and slightly narrower. This last result is contradicted by experimental results reported in Weaver and Dale (1978, reference *142*). Four responses of understory plants to the complex environmental gradient perpendicular to a trail are identified: increased presence along trails, decreased presence along trails, increased presence in the lightly disturbed part of the gradient, and no response to the gradient. Some of these responses are explained in terms of ecological changes along the trail and the narrowness of the disturbed zone along trails is stressed.

29. Davies, W.

1938. Vegetation of grass verges and other excessively trodden habitats. J. Ecol. 26:38-49.

This early description of plant communities which occur along roads and other heavily trampled locations in Great Britain illustrates the similarity of trodden vegetation in widespread localities. The most common survivors of heavy trampling were *Lolium perenne, Trifolium repens, Poa annua, Agrostis tenuis, Festuca ovina,* and *F. rubra.* This report is not highly appicable to the wilderness situation, but provides some insights into species resistance to trampling.

30. Dawson, J. O., D. W. Countryman, and R. R. Fittin. 1978. Soil and vegetative patterns in northeastern Iowa campgrounds. J. Soil Water Conserv. 33:39-41.

Comparison of neighboring sample plots in used and unused parts of campgrounds showed the following differences on the used sites: less soil macropore space, higher bulk density, higher pH, less soil organic matter, more grass cover, fewer plant species, less shrub cover, and more frequent crown dieback (on upland sites). Bottomland tree species, which naturally tolerate reduced soil aeration, apparently did not suffer from recreational use. Stand thinning and site hardening were suggested as means of reducing impacts.

31. Dawson, J. O., P. N. Hinz, and J. C. Gordon. 1974. Hiking trail impact on Iowa stream valley forest preserves. Iowa State J. Res. 48:329-337.

Soil and vegetative characteristics were measured, both on and along forested trails in Iowa. A dendrograph, based on similarity coefficients, suggested that more of the variability in ground cover composition resulted from natural site differences, either location of the study area or aspect, than from presence or absence of a trail. This is a surprising conclusion given the pronounced loss of cover, decrease in number of species, and increase in bulk density on trails which was also reported. Most of these changes were confined to 3 ft (1 m) on either side of the trail center. In addition, trails on north-facing slopes were less compacted and lost less ground cover than trails on flood plains or south-facing slopes. This may merely be a reflection of differences in amount of recreational use, however.

32. DeBenedetti, S. H., and D. J. Parsons. 1979. Mountain meadow management and research in Sequoia and Kings Canyon National Parks: a review and update. *In* Proc. Conf. on Sci. Res. in the Natl. Parks. p. 1305-1311. R. M. Linn, ed. U.S. Dep. Interior, Natl. Park Serv. Trans. Proc. Ser. 5, Gov. Print. Off., Washington, D.C.

This paper provides a general survey of impact problems in mountain meadows and available management techniques, with particular emphasis on Sequoia and Kings Canyon National Parks. Vegetation alteration and erosion following trampling and grazing, trail problems specific to meadows, and invasion of meadows by trees are all discussed. The conclusion is that management techniques have significantly improved meadow conditions in recent decades.

33. Devos, A., and R. H. Bailey. 1970. The effect of logging and intensive camping on vegetation in Riding Mountain National Park. For. Chron. 46:49-55.

The effects of intensive use on the vegetation of developed campsites in *Populus tremuloides* (aspen) and *Picea glauca-Pinus banksiana* (white spruce-jack pine) forests in Canada are briefly discussed. Aspen mortality resulting from mutilations is considered to be the most serious alteration. Over one-third of the undergrowth species on campsites were exotics. Some management implications are provided in the article.

34. Dotzenko, A. D., N. T. Papamichos, and D. S. Romine. 1967. Effects of recreational use on soil and moisture conditions in Rocky Mountain National Park. J. Soil Water Conserv. 22:196-197.

This paper summarizes the results of a more detailed study by Papamichos (1966, reference *103*).

35. Douglas, G. W., J. A. S. Nagy, and G. W. Scotter. 1975. Effects of human and horse trampling on natural vegetation, Waterton Lakes National Park. Unpubl. rep., Can. Wildl. Serv., Edmonton, Alta, 129 p.

The experimental trampling plots of Nagy and Scotter (1974, reference *101*) were reexamined after 1 year of recovery. Two limitations of the study, the authors note, were that pretreatment measurements were not taken on all plots and that the sampling intensity was too low. After 1 year of recovery, results show that *Picea engelmannii* (Engelmann spruce), *Xerophyllum tenax* (beargrass), and *Abies lasiocarpa* (alpine fir) communities show little recovery after trampling, even at low intensities; *Dryas octopetala* (alpine dryad) and *Pinus contorta* (lodgepole pine) communities show some recovery, but are sensitive to moderate levels of trampling; and lowland sedge marsh, lowland and upland *Populus tremuloides* (aspen), prairie grassland, and subalpine mesic meadow communities are capable of recovering after 1 year, except under the heaviest use. Some plant communities, however, had very different responses depending upon the frequency and timing of the trampling and the measure of change employed (percent cover or standing crop). Interestingly, this fragility ranking is very different from that of Nagy and Scotter (1974) who considered only the rate of deterioration. The report includes a good data set.

36. Duffey, E. 1967. The biotic effects of public pressure on the environment. Monks Wood Exp. Stn., Symp. 3, Nat. Conservancy, Huntingdon, Eng.

These proceedings contain a number of early papers on recreational impact. Relevant papers include: "Public pressures on soils, plants and animals near ski lifts in the Cairngorms" by A. A. Watson; "Human pressures on the mountain environment of Snowdonia" by R. Goodier; "Changes in chalk grassland caused by galloping" by F. H. Perring; and "Human impact on the fauna, flora, and natural features of Gibraltar Point" by J. M. Schofield. Most of these papers are either general in nature or provide only preliminary research results. Consequently, they are primarily of historical interest.

37. Dykema, J. A. 1971. Ecological impact of camping upon the southern Sierra Nevada. Ph.D. diss. Univ. Calif. Los Angeles. 156 p.

This study assesses campsite conditions in the different life zones (Upper Sonoran, Transition, Canadian, Hudsonian, and Arctic-Alpine) in and near Sequoia National Park, Calif. The most consistent differences between controls and camps were increased soil compaction and decreased herbs, leaf litter, and deadwood on camps. Seedlings were less abundant on some camps and tree mutilation was greater on some camps, but there was no evidence of differences in tree canopy cover. The lower two life zones exhibited the greatest amount of change, with the Upper Sonoran camps having large decreases in seedlings and herbs and increases in tree mutilation and soil compaction and the Transition zone camps having large losses of deadwood, leaf litter, and duff. The Arctic-Alpine zone had a large decrease in herbaceous cover, while the Canadian and Hudsonian zones were the least affected by camping. Car camping and backcountry camping were not separated, however; so that amount and type of use differs between zones.

Moreover, differences are expressed in absolute rather than relative terms. Some of the higher elevation zones have more pronounced relative changes than the lower elevation zones, even though they receive less use than the lower zones.

38. Echelberger, H. E.
1971. Vegetation changes at Adirondack campgrounds — 1964 to 1969. USDA For. Serv. Res. Note NE-142, 8 p. Northeast. For. Exp. Stn., Upper Darby, Pa.

Changes in campsite condition were measured over a 5-year period on developed campgrounds in the Adirondack Forest Reserve, N.Y. Use on the campgrounds ranged from 322 to 516 camper-days/tent site/year. Mean overstory density and vertical screening increased slightly, although there was considerable variability in the data. Lateral screening decreased slightly and 60 percent of the trees over 20 ft (6.1 m) tall were removed over the 5-year period. Deterioration and amount of use appeared to be unrelated. The conclusion was that well-maintained, developed campsites should not deteriorate much with continued use.

39. Emanuelsson, U.
1979. A method for measuring trampling effects on vegetation ("the circle sector method"). *In* The use of ecological variables in environmental monitoring. p. 91-94. Natl. Swed. Environ. Prot. Board, Rep. PM 1151.

This paper outlines an efficient design for experimental trampling studies. It also shows that heath vegetation is more susceptible to trampling damage than meadow vegetation.

40. Faliński, J. B.
1975. Die Reaktion der Waldbodenvegetation auf Trittwirkung im Lichte experimenteller Forschungen. [The reaction of forest ground cover to trampling in the light of experimental research.] Phytocoenologia 2:451-465. [In German, English summary.]

Experimental trampling was applied in an oak-linden-hornbeam forest and a continental pine-oak forest in Bialowieza National Park, Poland. Results include: more vegetation was lost during the second year of trampling than the first; luxuriant ground vegetation suffered greater losses (both absolute and relative) than sparse vegetation; the herb layer in the oak-linden-hornbeam forest disappeared more rapidly than that in the pine-oak forest, but it also recovered more rapidly; and bryophytes increased in biomass with trampling. This last conclusion contrasts with most reports.

41. Fenn, D. B., G. J. Gogue, and R. E. Burge.
1976. Effects of campfires on soil properties. Natl. Park Serv. Ecol. Serv. Bull. 5, 16 p. Washington, D.C.

Campfires altered organic matter to a depth of 4 in (10 cm) (90 percent loss in the 0- to 1-in zone) and often created a water repellent layer about 1 in (2.5 cm) below the surface. These effects are reduced under moist conditions, on fine-textured soils, and when softwoods are burned. The authors suggest concentrating all campfires in one place on each campsite, rather than moving them around.

42. Foin, T. C., Jr., ed.
1977. Visitor impacts on national parks: the Yosemite ecological impact study. Univ. Calif., Davis. Inst. Ecol., Publ. 10, 99 p.

This study of visitor use effects on some ecosystems in Yosemite National Park is most useful for research methods and for philosophical discussion of research approaches in relation to management policy. Specific results describe: vegetation change along meadow trails, with an increase in the prominence of some graminoids in heavily trampled zones; vegetation change in camps, where loss of ground cover, seedlings, and saplings was most important; and changes in bird and small mammal populations. More general conclusions were: trail formation in meadows occurs rapidly, but further deterioration is minimized because visitors stay principally on the trails; forested areas used for camping have been more seriously disturbed than meadows; and both comparative analysis and experimental research techniques are needed. (See Liddle [1975, reference *80*].)

43. Foin, T. C., Jr., E. O. Garton, C. W. Bowen, and others.
1977. Quantitative studies of visitor impacts on environments of Yosemite National Park, Calif., and their implications for park management policy. J. Environ. Manage. 5:1-22.

Republication of the most substantive chapter of Foin (1977, reference *42*).

44. Frissell, S. S.
1973. The impact of wilderness visitors on natural ecosystems. Unpubl. rep., 60 p. USDA For. Serv., For. Sci. Lab., Missoula, Mont.

This paper describes the condition of campsites in the Spanish Peaks Primitive Area, Mont. It includes a subjective site condition rating system based on a probable sequence of changes resulting from recreational use. Management prescriptions are provided for each condition class. The horse sites examined were 10 times larger than the hiker-only sites. They also had seven times as much exposed bare ground and had a median condition class of 4, as opposed to 2 for hiker camps (deterioration increases with increasing values up to 5). Camp size was not strongly correlated with condition class. The paper also contains a good discussion of research needs and an extensive bibliography.

45. Frissell, S. S., Jr., and D. P. Duncan.
1965. Campsite preference and deterioration in the Quetico-Superior canoe country. J. For. 63:256-260.

Campsite condition was evaluated on selected sites in the Boundary Waters Canoe Area, Minn. Campsites, in comparison with adjacent controls, lost an average of 85 percent of their original ground cover, 65 percent of the litter and humus layers, and all of their tree reproduction. Increases in root exposure and soil compaction were also noted. Most of these changes occurred with only light use (0 to 30 parties/season); further increases in use caused relatively insignificant additional change. This suggests that reducing use will do little to improve campsite conditions, while shifting use to unimpacted sites will cause significant change. Use was determined on the basis of personal observations and the opinions of local guides.

46. Gibbens, R. P., and H. F. Heady.
1964. The influence of modern man on the vegetation of Yosemite Valley. Calif. Agric. Exp. Stn. Ext. Serv. Man. 36, 44 p.

This report describes vegetation changes in Yosemite Valley resulting from human activities. It deals primarily with activities other than recreational use, but it does briefly discuss soil compaction and loss of vegetation, litter, and duff in heavily trampled areas.

47. Goldsmith, F. B.
1974. Ecological effects of visitors in the countryside. *In* Conservation in practice. p. 217-232. A. Warren and F. B. Goldsmith, eds. John Wiley and Sons, London.

This chapter provides a thoughtful discussion of problems with impact studies and a summary of basic results. It advances some ideas about what determines the sensitivity of ecosystems to recreational pressure. It is highly general.

48. Goldsmith, F. B., R. J. C. Munton, and A. Warren.
1970. The impact of recreation on the ecology and amenity of seminatural areas: methods of investigation used in the Isles of Scilly. Biol. J. Linn. Soc. 2:287-306.

This methodological paper discusses an investigation of recreational visitors' activities and impacts on the vegetation of the Isles of Scilly. Both large-scale mapping techniques and transects were utilized. Vegetation maps were compared to visitor distribution data obtained from questionnaire-maps. This revealed the vegetational preferences of visitors. By using partial coefficients to reduce the effects of environmental variability, detailed transect data showed that increased trampling leads to reductions in the cover of most plants, the maximum height of the vegetation, and the number of species in flower. The results are of limited applicability, because only 1 week of field work was involved, but a number of potentially useful methods are suggested.

49. Hartesveldt, R. J.
1965. An investigation of the effect of direct human impact and of advanced plant succession on *Sequoia gigantea* in Sequoia and Kings Canyon National Parks, California. Unpubl. rep., Natl. Park Serv., San Francisco. 82 p.

Reported here are some results of a study completed in 1963 for the University of Michigan, which is described in more detail in a dissertation by the author. Soil compaction was found to a depth of 8 in (20 cm), although it was greatest in the upper 2 in (5 cm). Growth rates of *Sequoiadendron giganteum* (giant sequoia) were *greater* on compacted areas than on noncompacted areas. This appeared to result from increased soil moisture and reduced understory competition in the compacted zone. Although not inhibitive to tree growth, this compaction may inhibit root growth by other species, and it creates unfavorable conditions for seed germination and seedling establishment.

50. Hartley, E. A.
1976. Man's effects on the stability of alpine and subalpine vegetation in Glacier National Park, Montana. Ph.D. diss. Duke Univ., Durham, N.C. 258 p.

A good detailed study of human impact on subalpine and alpine vegetation near Logan Pass in Glacier National Park, Mont. Studies along existing trails and experimental trampling at various intensities are included. Major findings include: trailside vegetation has fewer species, fewer "rare" species, less total cover, and less total flower production than adjacent undisturbed vegetation; the mean distance from trail center to natural vegetation is 9.8 $\pm$ 6.6 ft (3 $\pm$ 2 m); in experimental trampling, 15 tramples removed almost as much cover as 50 tramples, although recovery was slower in the latter case; little long-term damage occurs if meadows are trampled less than 5 times/week; cover loss was more rapid and recovery took longer in dry meadows than in wet meadows; and less utilizable carbohydrate in the roots of plants near trails suggests this may be a consequence of trampling and helps explain reductions in plant height, cover, and flower density. A sensitivity index based on each species' ability to grow near trails is provided. Related soil changes, primarily in bulk density and soil compaction, are also discussed. The author presents a wealth of data, collected over a period of 6 years, and makes some attempts at generalization. Additional interpretation is possible.

51. Hartley, E.
1979. Visitor impact on subalpine meadow vegetation in Glacier National Park, Montana. *In* Proc. Conf. on Sci. Res. in the Natl. Parks. p. 1279-1286. R. M. Linn, ed. U.S. Dep. Interior, Natl. Park Serv. Trans. Proc. Ser. 5. Gov. Print. Off., Washington, D.C.

Summary of research presented in more detail in Hartley (1976, reference *50*).

52. Hecht, S. B.
1976. Ecological carrying capacity research, Yosemite National Park. Part II. Human impact on subalpine ecosystems: microclimate. 27 p. U.S. Dep. Commerce, Natl. Tech. Inf. Cent. PB-270-956.

Microclimatic measurements, both on and off meadow paths, were taken in August. In all cases, ground and vegetation temperatures were higher and relative humidity was lower on paths. The percent decrease in relative humidity was greatest on paths in xeric meadows. There were no significant differences in percent increase in mean temperature between the five meadow types. Yet, the authors conclude that mesic meadows are the most highly altered in terms of microclimate.

53. Helgath, S. F.
1975. Trail deterioration in the Selway-Bitterroot Wilderness. USDA For. Serv. Res. Note INT-193, 15 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.

This study reports on how amounts of trail erosion in the Selway-Bitterroot Wilderness, Idaho, vary with site conditions and amount of use. The three major types of trail problems encountered were entrenchment by erosion, bog formation on perched or high water tables, and landslides on oversteepened slopes. Amount of trail erosion, measured as cross-sectional loss below a taut tape, was found to be highly related to vegetation type, landform, and trail slope. Aspect, elevation, parent material, and amount of use were not related to amount of erosion in any consistent way. Results should be applied with caution, however, because the cross-sectional area of a trail tread is highly dependent upon side slope and trail construction

practices, in addition to erosion. Management implications for various combinations of landform and vegetation type (biophysical units) are provided. The publication emphasizes that these locational implications and the lack of correlation between use and amount of erosion are significant.

54. Hinds, T. E.
1976. Aspen mortality in Rocky Mountain campgrounds. USDA For. Serv. Res. Pap. RM-164, 20 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

Populus tremuloides (aspen) was found to be highly susceptible to canker diseases following mechanical injuries caused by campers. On the 17 campgrounds studied, trees were dying at a rate of 3.6 $\pm$ 1.0 percent/year. The author concludes that camping areas should not be located in aspen groves, if an enduring forest cover is desired.

55. Hoffman, M. K.
1975. Quantification of vegetational change concomitant with recreational use. M.S. thesis. Univ. Guelph, Ont.

Most of this thesis deals with vegetation classification of Rushing River Park. Vegetative cover was measured on 41 campsites. It was concluded that *Populus tremuloides* (aspen) stands were more resistant to campsite impacts that *Pinus banksiana* (jack pine) stands. This thesis represents one part of the study reported in James and others (1979, reference *59*).

56. Holmes, D. O., and H. E. M. Dobson.
1976. Ecological carrying capacity research: Yosemite National Park. Part I. The effects of human trampling and urine on subalpine vegetation, a survey of past and present backcountry use, and the ecological carrying capacity of wilderness. U.S. Dep. Commerce, Natl. Tech. Inf. Cent. PB-270-955, 247 p.

This report discusses many issues related to backcountry impact. The authors conclude that human urine does not create significant problems. The most important section of the paper discusses the detailed results of experimental trampling. Each species trampled was assigned both a survival rate and a recovery rate. Separate survival rates were provided for different seasons of trampling. Other factors which influenced survival rates were soil, topography, and plant community structure and composition. For example, survival rates of the same species were generally about three times greater in mixed communities than in pure stands. Growth habitat and tissue strength were the vegetative characteristics which appeared to influence survival rates most. Herbaceous plants with basal leaves were the most resistant to trampling, while plants with woody parts and tall, herbaceous, caulescent plants were the most susceptible. Moist areas recovered the most rapidly and the species which recovered most rapidly were those with regenerative buds at or below the surface. A final section relates these experimental results to carrying capacity and management alternatives.

57. Hudson, M.
1977. Fortymile River: biological aspects of carrying capacity. Unpubl. rep. U.S. Dep. Interior, Bur. Land Manage., Tok, Alaska. 52 p.

Four study sites in tundra were each trampled a total of 50, 250, and 1,000 times in one summer season. Trails usually were visible after as few as five tramples, while 100 tramples gave the sites the appearance of "irreversible damage." Lichens and mosses were particularly susceptible. Path width and depth increased and annual production decreased as the number of tramples increased. Three subsequent studies, with continued trampling and recovery of these plots, have been undertaken. On some sites, visual recovery of the 1000x plots was complete after 1 year; on other sites, the 50x plots recovered less than 10 percent. Well-drained sites without much moss and lichen appeared to be most resistant to use. These reports contain a great amount of data but little interpretation. The rapid recovery on some of the heavily-trampled plots suggest that the oft-mentioned fragility of the tundra is an overgeneralization.

58. Ittner, R., D. R. Potter, J. K. Agee, and S. Anschell, eds.
1979. Recreational impact on wildlands [Conf. Proc., Oct. 27-29, 1978]. USDA For. Serv., Pac. Northwest Reg., R-6-001-1979, 333 p. Portland, Oreg.

Proceedings for this conference were available after the literature search for this bibliography was completed so no attempt has been made to review individual papers. There are several papers, however, pertinent to both impact and rehab ilitation in the backcountry. Topics include vegetation and soil restoration, impact prediction, methods of preventing impact, educating the visitor, and visitor perceptions of impact and rehabilitation. This is a good source of information.

59. James, T. D. W., D. W. Smith, E. E. Mackintosh, and others.
1979. Effects of camping recreation on soil, jack pine, and understory vegetation in a northwestern Ontario park. For. Sci. 25:333-349.

In comparison to undisturbed areas, developed campsites had greater penetration resistance, more frequent tree root exposure and damage to tree stems, thinner horizons, slower infiltration rates, reduced tree diameter and tree foliage growth, and dissimilar understory composition. When low- and high-use campsites were compared, the only pronounced differences were in penetration resistance, number of exposed roots, and trunk scars. Infilitration rates on campsites were only one-twentieth of those in the undisturbed areas, but there was little differences between low- and high-use sites. This is interesting because infilitration rates are probably one of the most important soil changes on campsites. Changes in understory vegetation included invasion of weedy exotic species, loss of fleshy species and lichens, height reduction, and loss of many shrubs and young trees. These changes became relatively unimportant more than 16.4 ft (5 m) from the bare central part of the campsite.

60. Johnson, D. W., and T. E. Hinds.
1977. Aspen mortality at the Maroon Lake Campground. Biological Evaluation R2-77-21. 18 p. For. Insect Dis. Manage., State Priv. For., USDA For. Serv., Lakewood, Colo.

Populus tremuloides (aspen) are dying at an accelerating rate in this popular campground in Colorado. Photographs and stand data are provided, as are some suggestions on how to slow the deterioration process and possibly to rehabilitate the site. (See Hinds [1976, reference *54*] for more discussion.)

61. Jones, D. H.

1978. The effect of pedestrian impact on selected soils. M.S. thesis. Univ. Glasgow, Scotland. 154 p.

This is a detailed experimental study of the effects of trampling on two coarse soils in Scotland. Experiments included: a one-time trampling at six intensity levels (16, 32, 64, 128, 256, and 512 passes) on both soils at four different moisture levels; weekly trampling at rates of 64 and 256 passes/week for 12 weeks; and 10 weeks of recovery after a one-time application of 64 and 256 passes. Physical properties measured were soil moisture content, surface configuration, resistance to torque, resistance to penetration, bulk density, and moisture release characteristics (a measure of macropore volume). Soil moisture often influenced the magnitude of changes in these properties to a greater extent than amount of trampling. The most significant effects of increased trampling were increases in path depth, soil resistance to torque and penetration, and decreases in the volume of macropores. Most of these changes occurred at low trampling intensities, by 64 to 128 passes, and during the first few weeks of the 12-week experiment. Recovery, however, was minimal after 10 weeks. The author stresses the significance of the rapid loss of over 50 percent of the macropores, which greatly reduces the movement of water and air. This loss is much greater where trampling occurs when the soil is moist. He suggests that closure for natural regeneration is not a viable alternative because of the rapid degradation and slow recovery and that, in certain cases, questioning how much use is appropriate has little value, because any use causes most of the damage. This study includes a good literature review, discussion of methods, and suggestions for further research.

62. Kalisz, S. P., and J. H. Brown, Jr.

1976. Starch content of oak roots on campsites. Sci. Biol. J. (July-August): 160-165.

Starch levels in roots of oak trees (*Quercus alba, Q. velutina,* and *Q. coccinea*) were measured on and off campsites in Rhode Island. Only *Q. coccinea* showed any differences between campsites and control sites. It exhibited lower levels of starch on campsites, but only during a dry year. This was also the only species that showed reduced annual height growth on campsites. There were no apparent reductions in diameter growth. This suggests that campsite use has little effect on tree growth, except in the case of *Q. coccinea*. The authors note that more work is needed before any definite conclusions can be drawn.

63. Kazanskaya, N. S.

1977. Forests near Moscow as territories of mass recreation and tourism. Urban Ecol. 2:371-395.

The process of "forest retrogression" as a result of recreation use in forest stands near Moscow, USSR, is described. Increases in soil density, decreases in water permeability and litter, changes in the composition of the herbaceous layer, and loss of both young and mature trees are documented. Five stages of retrogression were identified, with the loss of regenerative ability under constant recreational pressure occurring between stages III and IV. Using this as the limit of permissible recreational pressure, birch and oak forests are shown to have higher recreational capacities than spruce forests. Seminatural "dense forest-clearing" complexes can absorb heavy recreational use. An interesting attempt to provide a rational basis for ecological carrying capacity determinations.

64. Kellomäki, S.

1973. Tallaamisen vaikutus mustikkatyypin kuusikon pintakasvillisuuteen. [Ground cover response to trampling in a spruce stand of Myrtillus type.] Silva Fenn. 7:96-113.

This paper describes the effects of simulated trampling, with a mechanical tamp, on the ground cover of a *Picea abies-Vaccinium myrtillus* (spruce-blueberry) forest in Finland. Tamping rates were 0, 1, 4, 16, and 64 tamps/plot/week, for 8 weeks. Forb cover was destoryed more rapidly than that of dwarf shrubs or grasses. Even slight trampling caused noticeable changes, with the most dramatic increases in cover loss occurring between 1 and 4 tamps/week and between 16 and 64 tamps/week.

65. Kellomäki, S.

1977. Deterioration of forest ground cover during trampling. Silva Fenn. 11:153-161.

Experimental trampling, at rates of 0, 4, 16, 32, and 64 tamps/week, for 7 weeks, was applied in three coniferous forests and a meadow in Finland. Decay function curves of biomass loss are provided, although from the description in the text, it appears that the figure captions have been misplaced. Rate of deterioration was most rapid on the infertile *Calluna* site type, primarily because of the fragile lichen layers present. In the meadow, 50 percent of the cover was lost almost as rapidly as in the forest (5-10 tamps/week). In the meadow, the equilibrium level, at which further trampling causes no additional deterioration, occurs between 60 and 70 percent biomass loss, compared to between 80 and 90 percent loss in the forests. The author argues that this superior ability of the grass-herb meadow to tolerate trampling may become even more pronounced with longer term trampling due to the ability of secondary vegetation to invade meadows. The suggestion is that the vegetation on fertile sites and meadows is especially tolerant of trampling.

66. Kellomäki, S., and V. L. Saastamoinen.

1975. Trampling tolerance of forest vegetation. Acta For. Fenn. 147:5-19.

Simulated trampling, using a mechanical tamp, was applied to five different vegetation types (three coniferous forests and two grasslands) in Finland. A trampling tolerance level was then assigned to each plant community and major plant species based on the rate that cover and biomass are removed as trampling increases. Lichens were particularly susceptible to trampling, as were dry sites compared to moist sites. In the coniferous forests, the moderately fertile site was more tolerant than the highly fertile site, which was more tolerant than the site with low fertility. Camping in meadows is considered to be the best solution to minimizing long-term damage, because resistant species invade meadows as trampling continues. An interesting approach, but the use of simulated trampling and the mathematical assumptions should make one cautious of directly applying the results.

67. Ketchledge, E. H., and R. E. Leonard.

1970. The impact of man on the Adirondack high country. The Conservationist 25(2):14-18.

This paper describes trail erosion and the destruction of alpine communities in the Adirondack Mountains of New York. Four stages of trail erosion are identified and measurements indicate that many trails are increasing in both width and depth at a rate of 1 inch/year (2.5 cm/yr). The authors briefly describe experiments designed to determine possible means of supplementing the deteriorated sphagnum moss tundra found on mountaintops with more trampling-tolerant nonnative species. They report 70 to 90 percent success with seeding grasses, where fertilizer is applied concurrently.

68. Kregosky, B., E. Nowick, D. Parsons, C. Watson, and F. Marsh.

1972. Great Divide Trail survey, 1971; an ecological investigation of the proposed route. (Two vols.) Unpubl. rep., Can. Wildl. Serv., Edmonton, Alta.

This survey of existing and potential impacts along the Great Divide Trail in the southern Canadian Rockies is mostly site specific, but it provides some general information on site conditions that contribute to trail deterioration problems. The most severe problems were found in areas with poorly drained soils. Other problems were found in areas of late snowmelt, on talus slopes with active downslope movement, and where trails climb streambanks vertically. The soils most capable of supporting trails were loams, with a crumb or blocky structure and a moderate amount of organic matter.

69. Laing, C. C.

1961. A report on the effect of visitors on the natural landscape in the vicinity of Lake Solitude, Grand Teton National Park, Wyoming. Unpubl. rep., 62 p. Natl. Park Serv., Grand Teton Natl. Park, Wyo.

Site-specific observations on trail, campsite, and grazing impacts provide some insights into general problems and offer some feasible solutions. The most severe trail problems resulted from horse use and use when trails were wet. The least amount of alteration occurred in dry meadows. Lack of ground cover and tree reproduction to replace the overstory were the major campsite problems. Grazing appeared to have surprisingly little effect, except for trampling when the soil was wet. The advantages of restricting the spatial distribution of use are discussed.

70. Landals, A. G., and L. J. Knapik.

1972. Great Divide Trail: an ecological study of the proposed route, Jasper National Park and vicinity. Unpubl. rep., 251 p. Can. Wildl. Serv., Edmonton, Alta.

This study presents an excellent way to assess current and potential impact problems along a trail. Brief results of experimental trampling were incorporated, along with consideration of soil texture, drainage, slope steepness, and topography, into a table of fragility ratings. The ratings were then applied to 227 mi (363 km) of trails, with recommendations for trail maintenance techniques, where to establish campsites, and where the trail needs to be relocated. This discussion is followed by a section on general recommendations for trail planning, construction, and management. The authors emphasize the need for use concentration at designated campsites and the fact that rest-rotation of campsites is not feasible. The study is highly applicable to trail and campsite planning.

71. Landals, M., and G. W. Scotter.

1973. Visitor impact on meadows near Lake O'Hara, Yoho National Park. Unpubl. rep., 184 p. Can. Wildl. Serv., Edmonton, Alta.

Comparisons of used and unused sites and experimental trampling were used to assess human impact on subalpine meadows in the Rocky Mountains of British Columbia. Much of the information, such as species resistance, is site specific in value, but useful generalizations include: fire scars were more rapidly recolonized when the rocks were left in place; community differences disappeared following trampling because *Carex nigricans* and *Sibbaldia procumbens* dominated essentially all disturbed sites; the impact of trampling frequency depended upon trampling intensity, with trampling spread out over time being less damaging at low trampling levels and concentrated trampling less damaging at high trampling levels (>100 walks in this study); enclosures suggested that reestablishment of a complete cover in the meadows would be rapid; and meadows were less fragile for camping than forest vegetation, but the authors felt that because of scenic attraction of the meadows, they should not be used for camping. This report is a good survey of the situation, although the adequacy of the controls used in both the experimental and comparison studies should be questioned, given the great compositional diversity and heterogeneity of subalpine meadows.

72. Landals, M., and G. W. Scotter.

1974. An ecological assessment of the Summit Area, Mount Revelstoke National Park. Unpubl. rep., 197 p. Can. Wildl. Serv., Edmonton, Alta.

This report is a good, thorough assessment of recreational impacts on an area in the Rocky Mountains of British Columbia. Plant communities were described, mapped, and each assigned a fragility rating based on response to experimental trampling. Visitor use was described, as were current impacts. Surprisingly little damage was noted, aside from a proliferation of trails. Results of the experimental trampling showed that *Vaccinium membranaceum, Valeriana sitchensis,* and *Cassiope mertensiana* communities were highly susceptible to damage from trampling, with more than 50 percent of their cover being destroyed by 25 to 100 tramples; *Luetkea pectinata* and *Carex nigricans* communities were more resistant; and weekly trampling was usually more destructive than one-time trampling in the early summer (much of this difference may have resulted from recovery after early summer trampling). An index of vegetation fragility is provided, but it should be used cautiously; a follow-up study, by Campbell and Scotter (1975, reference *201*) showed a need to revise the rankings. Land managers are cautioned that, for the same piece of land, fragility ratings based on soils may contradict ratings based on vegetation and that intensive use will inevitably destroy all vegetation, regardless of fragility ratings. If this intensity of use is anticipated, soil fragility should be given more consideration than vegetation rankings.

73. LaPage, W. F.

1962. Recreation and the forest site. J. For. 60:319-321.

Some ecological effects of camping in three New Hampshire State Parks were evaluated by comparing sample plots on campsites with neighboring unused controls. Soil compaction (penetration resistance) appeared to increase with intensity and duration of use, although it was not possible to adequately differentiate between the effects of site differences and of use differences. On the heavy-use sites, compaction was greatest 2 to 6 in (5 to 15 cm) below the surface. An apparent reduction in the diameter growth of *Pinus strobus* (white pine) growing in heavily used areas was also noted. This observation should be considered with caution, however, because this reduction could result from factors other than recreational use.

74. LaPage, W. F.

1967. Some observations on campground trampling and ground cover response. USDA For. Serv. Res. Pap. NE-68, 11 p. Northeast. For. Exp. Stn., Broomall, Pa.

This study followed the process of change in ground cover vegetation during the initial 3 years of a campground in the Allegheny National Forest, Pa. Existing vegetation was a treeless, abandoned field of grasses and forbs. During the first year of use, percent vegetative cover and the number of species decreased, with cover loss being greatest on the most heavily used sites. A threshold level was identified at about 200 camper-days, above which increased use resulted in much greater cover loss. By the end of the third year, cover was greater than at the end of the first, although the number of species continued to decline. By this time, there was no relationship between cover and either annual or cumulative use; some of the most lightly used sites had experienced the greatest amount of cover loss. The author concluded that an "initial and inevitable" cover loss occurs, which is related to amount of use, but that surviving cover in subsequent years is not related to amount of use (as long as some use occurs). Increases in cover after the first year resulted from the invasion or increased importance of trampling-resistant species. Grasses and "small plants" were more resistant than "tall plants," "dicots," and mosses. This is one of only a few studies of how campsite conditions change through time following their initial development.

75. Legg, M.

1973. Site factors useful in predicting deterioration of forest campsites in northern Michigan. Ph.D. diss. Mich. State Univ., East Lansing. 99 p.

Changes in soil and litter characteristics were monitored for 2 years on existing campsites (used for 2 years previously) and experimental trampling plots in northern Michigan. Generally, decreases in litter cover, depth, and weight, noncapillary pore space, and depth of the AO horizon were associated with increased campsite use and trampling intensity. Bulk density increased with trampling intensity, but was not related to amount of use on existing campsites; apparently maximum densities had already been reached on some sites. Sites with thick litter layers and AO horizons were less highly altered. Consequently, conifer sites were more durable, particularly at low-use levels, than hardwood sites. Campsite size increased over the period, but there was no consistent relationship between this increase and amount of use. Moreover, there was no relationship between campers' perception of campsite condition and either measured ecologic changes or amount of use. Recovery during 1 year on closed sites was insufficient to consider mere closure a viable means of site rehabilitation. Multiple regression equations were developed in order to assess the importance of site factors in predicting amount of change. Most of the material in this dissertation is site specific and dependent upon site and use history variables.

76. Legg, M. H., and G. Schneider.

1977. Soil deterioration on campsites: northern forest types. Soil Sci. Soc. Am. J. 41:437-441.

Percent organic litter cover, bulk density, macropore space, and depth to the A2 horizon were measured over two seasons on Michigan campsites which had been open for two seasons previously. Lightly used (100 to 150 visitor days/year), moderately used (200 to 250), and heavily used sites (300 to 500) in both hardwood and conifer stands were compared. Some of the results included: increased change in each parameter was associated with increased use; except in the case of depth to the A2 horizon. there are much greater differences between light-use sites and controls than between light- and heavy-use sites; depth to the A2 horizon will be reduced to zero within a few years on all campsites, regardless of use level; and except for depth to the A2 horizon, some winter recovery occurs, but this is usually offset by early July. The data presented in this publication suggest that most of the possible deterioration occurs within the first 5 years of use. (Compare with Merriam and others [1973, reference *98*].)

77. Lemons, J.

1979. Visitor use impact in a subalpine meadow, Yosemite National Park, California. *In* Proc. Conf. on Sci. Res. in the Natl. Parks. p. 1287-1292. R. M. Linn, ed. U.S. Dep. Interior, Natl. Park Serv. Trans. Proc. Ser. 5. Gov. Print. Off., Washington, D.C.

Vegetative attributes and soil compaction were measured along a gradient of light to heavy use. *Muhlenbergia filiformis* and *Carex exserta* increased in prominence with increased use, while all other species decreased. The author stresses the nonsystematic nature of these changes and suggests that the response of individual plant species to human use has only qualitative predictive value. He suggests using a measure of community responses as a predictor of change. The coefficient of community, he suggests, is similar to the floristic dissimilarity value used by Cole (1978, reference *24*).

78. Leney, F. M.

1974. The ecological effects of public pressure on picnic sites. J. Sports Turf Res. Inst. 50:47-51.

A good, but brief, summary of a thesis which included observations of existing picnic sites in northeast Scotland and experimental trampling in the greenhouse and in the field. The most trampling-resistant plant communities had developed on what formerly were acid grassland and dry heather moor communities. The most resistant "natural" plant community was a grassland, which occurred on the lee side of dunes. Wet areas were usually denuded at lower trampling intensities than dry areas, and the ground cover of forests was much more susceptible than that of open areas. Experimental trampling in the greenhouse showed variable responses to trampling at the species level and even by different morphological types within one species. Moreover, these responses often differed markedly from responses in the field where the plant is competing with others, indicating that species response is highly variable, depending upon characteristics of the site and associated vegetation. On highly susceptible *Ammophila* dune grass sites, the effect of just 10 minutes of sitting was noticeable 2 years later. Recovery of picnic sites was much more rapid where some ground cover remained. On these sites, productivity approached normal levels within 1 year, although return to a normal species composition was slow and effects on the soil were considered largely irreversible.

79. Lesko, G. L., and E. B. Robson.

1975. Impact study and management recommendations for primitive campgrounds in the Sunshine-Egypt Lake Area, Banff National Park. North. For. Res. Cent. Inf. Rep. NOR-X-132, 86 p. Edmonton, Alta.

This report contains good, site-specific observations on campsite conditions in a heavily used backcountry area of subalpine forests and meadows in the Rocky Mountains of Alberta, Can. Each campsite was assigned a capability rating and an impact state, with criteria given for assigning quantitative values to each. Management recommendations are offered which take these ratings and use patterns into account. The authors suggest that subalpine meadows on alluvial fans or terraces with rocky soils can tolerate the most recreational use because they have thick Ah horizons, no restrictions to rooting depth, and are dominated by trampling-resistant grasses. Essentially no impact was detected away from the campsites and trails. This report is most useful for its methodology and the capability rating (discussed in greater detail in reference *170* by Lesko [1973]).

80. Liddle, M. J.

1975. A selective review of the ecological effects of human trampling on natural ecosystems. Biol. Conserv. 7:17-36.

An excellent review of trampling research approaches and conclusions and how this information can be applied to management situations. Although it contains too much information to adequately review, some of the major conclusions include: trampling generally results in reduced vegetative cover and species richness (the number of species in an areal unit); trampling increases the bulk density and penetration resistance of soil; and trampling causes significant changes in the species composition of both plant and animal populations. The examples provide a good introduction to the study of the ecological effects of human trampling.

81. Liddle, M. J.

1975. A theoretical relationship between the primary productivity of vegetation and its ability to tolerate trampling. Biol. Conserv. 8: 251-255.

This paper reviews major generalizations about the effects of human trampling on vegetation and advances the hypothesis that trampling tolerance increases with the primary productivity of an ecosystem. Data are presented which show some support for this relationship, when tolerance is defined as the amount of pressure it takes to reduce cover to 50 pecent of its original amount. Alternative definitions of tolerance may be more applicable to some management situations, however.

82. Liddle, M. J., and P. Greig-Smith.

1975. A survey of tracks and paths in a sand dune ecosystem. I. Soils. II. Vegetation. J. Appl. Ecol. 12:893-930.

This study details vegetation and soil conditions associated with footpaths and vehicular tracks in a sand dune area of North Wales, utilizing experimental trampling and observations along existing paths. Bulk density and penetration resistance were higher on paths than in adjacent unused areas. Experimental trampling showed that as trampling intensified, further trampling caused less significant increases in soil compaction. Soil water content was abnormally high on tracks in dry areas and low on tracks in wet areas. The general effect of trampling on the vegetation was to produce more uniform stands, with reduced cover and number of species. Total biomass was greatest at path margins, in areas which received low levels of trampling. The paper also discusses the responses of individual species and growth forms to trampling. This was a well-conceived, detailed study which may be useful for methods and some broad generalizations, particularly in other coastal sand dune areas.

83. Liddle, M. J., and K. G. Moore.

1974. The microclimate of sand dune tracks: the relative contribution of vegetation removal and soil compression. J. Appl. Ecol. 11:1057-1068.

One of the indirect effects of trampling is to alter the microclimate as a result of soil compaction and vegetation removal. They report that on a dry sand dune track in North Wales, the diurnal soil temperature range increased 7° C, the result of a counteraction between the tendency of vegetation loss to increase temperature ranges and of soil compaction to decrease temperature ranges. This effect was less pronounced in moist areas and increases in air temperature ranges were less pronounced than increases in soil temperature ranges. Increases in windspeeds over the track were also noted.

84. Lime, D. W.

1972. Large groups in the Boundary Waters Canoe Area — their numbers, characteristics, and impact. USDA For. Serv. Res. Note NC-142, 4 p. North Cent. For. Exp. Stn., St. Paul, Minn.

The author speculates that large groups cause more resource impacts than smaller groups because larger campsites are needed and because studies show that large groups tend to be more mobile and to stay longer. These suggestions are open to debate, however.

85. Lutz, H. J.

1945. Soil conditions of picnic grounds in public forest parks. J. For. 43:121-127.

The soils of picnic sites and adjacent controls in Connecticut State Parks were compared. On picnic sites, soil density was significantly greater, a result of a measured decrease in pore volume. Most of this decrease was a loss of noncapillary pore space, so that air capacity was significantly decreased, while field capacity remained constant on the sandy soil and increased on the sandy loam soil. These results suggest that aeration should be more of a problem than water deficiencies. Management suggestions include less removal of annual litter fall, rotation of sites, and artificial loosening of the soil.

86. McCool, S. F., L. C. Merriam, Jr., and C. T. Cushwa.

1969. The condition of wilderness campsites in the Boundary Waters Canoe Area. Minn. For. Res. Note 202, 4 p. Univ. Minn., St. Paul.

Increases in soil penetration resistance and decreases in duff depth were greater on island sites than mainland sites, while campsites on major canoe routes were larger, more highly compacted, and had greater reductions in duff depth than more remote sites. No consistent relationship to campsite location was found for vegetation cover, damage to trees, or trash. It was not possible to determine which of these differences were due to site differences and which were due to differences in use intensity.

87. McQuaid-Cook, J.

1978. Effects of hikers and horses on mountain trails. J. Environ. Manage. 6:209-212.

This paper provides an overview of recreational impacts on trails. Processes of trail degradation are discussed, as are some differences between horse and hiker impacts. The author

states, for example, that equestrian trails are usually less compacted and more deeply entrenched than pedestrian trails. No data are provided, however.

88. Magill, A. W.

1970. Five California campgrounds . . . conditions improve after five years' recreational use. USDA For. Serv. Res. Pap. PSW-62, 18 p. Pac. Southwest For. and Range Exp. Stn., Berkeley, Calif.

This paper describes changes in conditions over 5 years on five developed campgrounds in California. Over this period of time, no changes in tree density or growth rates were noticed. Undergrowth cover and litter cover and depth increased during the period. Unused sites, however, still had greater amounts of seedlings, saplings, shrubs, screening, and litter. Nevertheless, these observations suggest that the condition of established campsites does not continue to deteriorate through time. This conclusion must be tempered by the facts that barrier systems were erected at the beginning of the study period to keep vehicles off the sites and precipitation was above average or increasing over the period.

89. Magill, A. W., and E. C. Nord.

1963. An evaluation of campground conditions and needs for research. USDA For. Serv. Res. Note PSW-4, 8 p. Pac. Southwest For. and Range Exp. Stn., Berkeley, Calif.

One hundred thirty-seven developed Forest Service camping and picnic sites in California were surveyed. Tree seedlings were absent on 55 percent of the camps and even where present, their continued survival appeared to be doubtful. Twenty-eight percent of the overstory trees exhibited "poor vigor" and many of the vigorous trees had been mutilated by campers. Grasses and forbs were entirely absent on 95 percent of the individual units. On more than 70 percent of the sites, evidence was found of soil deterioration including hard-packed surfaces, small alluvial fans, rills and gullies, soil lines on tree bases, exposed roots, and exposed underground parts of camp facilities. Some *Abies procera* (noble fir) and *Abies concolor* (white fir) also had reduced diameter growth. Provides a general survey of conditions which suggest some apparent effects of use.

90. Malin, L., and A. Z. Parker.

1976. Ecological carrying capacity research: Yosemite National Park. Part III. Subalpine soils and wilderness use. 89 p. U.S. Dep. Commerce, Natl. Tech. Inf. Cent. PB-27-957.

Four types of subalpine soils were studied. It was concluded, apparently on the basis of observations and theoretical considerations, that wet meadow soils are most susceptible to damage and that better-developed soils on forested moraines can best tolerate use. Use of campsites on developed soils "seems to cause a structure alteration (compacted pan) which renders the soil more stable in the face of increased impact." Gravelly soils were not highly compacted due to their coarse texture. There is no data interpretation in the text, but a great amount of site-specific data have been included in the appendix.

91. Manning, R. E.

1979. Impacts of recreation on riparian soils and vegetation. Water Resour. Bull. 15:30-43.

Good overview of recreational impacts on soils and vegetation. The sections on spatial and temporal patterns are particularly useful. The author emphasizes that recreational impacts are highly concentrated but that impacted areas tend to expand with time. This suggests that impacted areas should be concentrated in areas of "high resource capability" and that managers should attempt to confine the spread of impacts. The author also notes that most impacts occur very rapidly and with very little use; therefore impacts are inevitable and, in many cases, cultural treatment of the vegetation will be necessary.

92. Marnell, L., D. Foster, and K. Chilman.

1978. River recreation research conducted at Ozark National Scenic Riverways 1970-1977: a summary of research projects and findings. U.S. Dep. Interior, Natl. Park Serv., Van Buren, Mo. 139 p.

This report contains chapters on such diverse topics as counting river users, social characteristics of users, and safety aspects of river recreation. The chapter on soil and vegetation impacts documents the same types of impacts frequently discussed elsewhere (soil compaction, change in species composition of the vegetation, and damage to trees).

93. Meinecke, E. P.

1928. The effect of excessive tourist travel on the California redwood parks. Calif. Dep. Natl. Resour., Div. Parks, Sacramento. 20 p.

This very early impact study reports some effects of recreational use on the root system of *Sequoia sempervirens* (redwood). In heavily impacted areas, the author noted decreases in the number of feeder roots and the frequency of branching, and changes in the vertical distribution of roots. This report is mostly of historical value.

94. Merkle, J.

1963. Ecological studies of the Amphitheater and Surprise Lakes cirque in the Teton Mountains, Wyoming. Unpubl. rep., 25 p. Natl. Park Serv., Grand Teton Natl. Park, Wyo.

This report is primarily concerned with describing the vegetation of this subalpine area. Some observations of recreational use and impact are included, however. The author emphasizes the highly localized nature of impacts and recommends regulation of packstock use such that this situation continues. Some data on species abundance in used and unused meadows are presented. There is, however, no indication of how similar these locations were environmentally.

95. Merkle, J.

1964. Ecological studies in Holly Lake cirque of the Teton Mountains, Wyoming. Unpubl. rep., 29 p. Natl. Park Serv., Grand Teton Natl. Park, Wyo.

Although the primary concern of this report is to describe the subalpine vegetation of the area, visitor use and resulting impacts are also briefly described. The author recommends containing impact by building hitch racks and "developed" campsites. This report is mostly site specific in value.

96. Merriam, L. C., Jr., and C. K. Smith.

1974. Visitor impact on newly developed campsites in the Boundary Waters Canoe Area. J. For. 72:627-630.

This article summarizes research reported in more detail in Merriam and others (1973, reference *98*).

97. Merriam, L. C., Jr., and C. K. Smith.

1975. Newly established campsites in the BWCA, restudy of selected sites—1974. Minn. For. Res. Note 254, 4 p. Univ. Minn., St. Paul.

This paper reports remeasurements taken on five campsites, 2 years after the study reported in Merriam and others (1973, reference *98*). No marked changes over the 2 years were noted, although some sites continued to deteriorate slowly while others improved. As the authors state, however, "The sample size was too small to make any real inferences." The possibility of using shrubs to prevent site expansion and wood chip mulch to reduce compaction is mentioned.

98. Merriam, L. C., Jr., C. K. Smith, D. E. Miller, and others.
1973. Newly developed campsites in the Boundary Waters Canoe Area — a study of five years' use. Univ. Minn. Agric. Exp. Stn., St. Paul, Bull. 511, 27 p.

Changes in soil penetration resistance, organic matter, vegetation cover, tree damage, and site size were monitored for 5 years and related to use intensity on 33 newly developed wilderness campsites. Results showed that the greatest increase in soil compaction occurred during the first 2 years, with little additional increase during the remaining 3 years of observation. The most striking change over time was not the increased **intensity** of any type of disturbance, but the increased **area** of disturbance. Several patterns of campsite expansion are discussed along with possible explanations for their development. Summary impact stages were calculated for each site and related to use levels. In general, impact increased with use in each vegetation type, but the relationship was highly curvilinear. Most impact occurred at low-use intensities, and in some vegetation types low use produced more impact than heavy use in other vegetation types. One should be cautious in interpreting these results, however, because the measured changes cannot be related to conditions existing prior to site construction. The fact that most impact occurs in the first 2 years the camp is used, while recovery takes much longer, suggests that campsite rotation would be self-defeating.

99. Monti, P., and E. E. Mackintosh.
1979. Effect of camping on surface soil properties in the boreal forest region of northwestern Ontario, Canada. Soil. Sci. Soc., Am. J. 43:1024-1029.

In comparison with undisturbed areas, campsites have lost their surface leaf litter horizons. Some of this organic matter is incorporated into the A1 horizons. Furthermore, the compacted surface mineral horizon on campsites is characterized by a reduction in both total porosity and noncapillary pore space. These changes are most pronounced more than 1 cm below the surface and are more evident on *Pinus banksiana* (jack pine) sites than on *Populus tremuloides* (aspen) sites.

100. Moorhead, B. B., and E. S. Schreiner.
1979. Management studies of human impact at backcountry campsites in Olympic National Park, Washington. *In* Proc. on Sci. Res. in the Natl. Parks. p. 1273-1278. R. M. Linn, ed. U.S. Dep. Interior, Natl. Park Serv. Trans. Proc. Ser. 5, Gov. Print. Off., Washington, D.C.

This paper describes a backcountry campsite impact inventory undertaken in Olympic National Park. It discusses results which also appear in Schreiner and Moorhead (1976, reference *115*). Again the authors stress the need to give individual site management a higher priority.

101. Nagy, J. A. S., and G. W. Scotter.
1974. A quantitative assessment of the effects of human and horse trampling on natural areas, Waterton Lakes National Park. Unpubl. rep., 145 p. Can. Wildl. Serv., Edmonton, Alta.

This report presents results of a one-season experimental trampling study in 10 plant communities in the Rocky Mountains of Alberta. Each community was subjected to one-time early summer, one-time midsummer, and weekly trampling for 5 weeks, at levels of 0, 25, 50, 100, 200, 300, 400, and 800 total tramples. Results indicated that lowland marsh and lowland and upland *Populus tremuloides* (aspen) communities were highly fragile; *Pinus contorta* (lodgepole pine), *Picea engelmannii* (Engelmann spruce), and *Abies lasiocarpa-Larix Lyallii* (alpine fir-alpine larch) were moderately fragile; subalpine lakeshore, *Dryas octopetala* (dryad), *Xerophyllum tenax* (beargrass), and prairie grassland communities were the most durable; in the prairie grassland, where horse and hiker impact were compared, horses destroyed three to eight times as much cover and created an order of magnitude more bare ground; in most cases, the greatest damage occurred with low levels of trampling; differences caused by the timing of trampling were generally less important than differences attributable to amount of trampling; and grasses and sedges were more resistant to trampling than dicotyledonous herbs and shrubs. This report provides a good data set, but one must keep in mind the short data collection period (recovery could not be considered) and the heterogeneity of the sample stands (trampled areas had to be compared to untrampled stands with somewhat different species composition). For a followup study with somewhat different results see Douglas and others (1975, reference *35*).

102. Palmer, R.
1972. Human foot impact: a preliminary report of the effects of human traffic on two alpine meadows in the Sierra Nevada. *In* Wilderness impact study report. p. 15-25. H. T. Harvey, R. J. Hartesveldt, and J. T. Stanley, eds. Sierra Club Outing Comm., San Francisco, Calif.

Preliminary results of experimental trampling suggest that meadow vegetation can be stepped on up to about five times before it is noticeably damaged. Two hundred tramples reduced total cover by only 6 percent, although stem breakage occurred after approximately 90 tramples. In *Phyllodoce breweri* heath, damage is obvious after 50 tramples, and after 210 tramples 90 to 95 percent of the plants had been destroyed. This suggests that the heather areas are more susceptible to trampling than grass-sedge meadows. No difference between the impact of lug soles and flat shoes was noticed. Few data are provided here, but a more detailed final report can be found in Stanley and others (1979, reference *124*).

103. Papamichos, N. T.
1966. Campground vegetative study, Rocky Mountain National Park, Colorado. Unpubl. rep., 101 p. Natl. Park Serv., Rocky Mt. Natl. Park, Colo.

This more detailed presentation of the results reported in Dotzenko and others (1967, reference *34*) includes a good review of the soil compaction problem. Depth of soil compaction exceeded 4 in (10 cm) on heavily used campsites. In comparison to essentially undisturbed parts of the campground, heavily used sites had higher bulk densities and lower organic matter and moisture content. There were cases, however, where organic matter and moisture content were higher on the used sites. In all cases, there was a much greater difference between essentially unused and moderately used parts of the campground than between moderate- and high-use areas. A negative correlation between organic matter and bulk density was reported as support for the statement that soils high in organic

matter were less readily compacted than soils low in organic matter. While this may be true, the correlation reported is primarily a result of similar responses by both variables to differences in trampling intensity; no correlation exists when the data are stratified by use intensity. The author's conclusion is that the best sites for development have medium-textured, well-drained, fertile soils, which are high in organic matter.

104. Peters, J. E.
1972. The ecological implications of trail use, Cypress Hills, Alberta. M.S. thesis. Univ. Alberta, Edmonton. 159 p.

Trails, in contrast to adjacent areas, had higher bulk density and pH, and lower organic matter, moisture content, and air-filled pore space values. The vegetation along trails also differed from that in undisturbed areas, with only two annuals, *Polygonum aviculare* and *Matricaria matricarioides*, surviving on the usually bare trail tread. At the trail edge, typical native species are largely replaced by weedy invaders, such as *Poa interior* and *Taraxacum officinale*. This thesis is most useful for its review of possible consequences of these changes and the pros and cons of various measurement techniques.

105. Rechlin, M. A.
1973. Recreational impact in the Adirondack high peaks wilderness. M.S. thesis. Univ. Mich., Ann Arbor. 65 p.

Backcountry campsites were studied and user perceptions were surveyed. The campsite investigations were not detailed, although it was possible to conclude that the areal extent of bare ground and disturbed forest increased with increasing use of the campsites. Most of this change occurred at the lower use levels. It was estimated that only 23.79 acres (9.63 ha) of the 219,570-acre (88 926-ha) area had been disturbed by camping. While this acreage is small, this is where people spend most of their time.

106. Rees, J., and J. Tivy.
1978. Recreational impact on Scottish lochshore wetlands. J. Biogeogr. 5:93-108.

A variety of interesting methods are integrated in an attempt to assess recreational impact and the relative vulnerability of lakeshore plant communities. It was concluded that walking causes more impact than running and that most species are damaged by trampling. The correlation between damage and trampling intensity was high, but not perfect. Vulnerability appeared to be more a function of shoot response (growth-form and leaf resistance) than root or rhizome response. Each species responded quite distinctively to trampling, however.

107. Ripley, T. H.
1962. Recreation impact on southern Appalachian campgrounds and picnic sites. USDA For. Serv. Res. Pap. SE-153, 20 p. Southeast, For. Exp. Stn., Asheville, N.C.

Multiple regression analysis related eight dependent variables to 18 independent variables on 280 developed camp and picnic sites in the southern Appalachians. The most important relationship for all sites studied was an association between increased high canopy closure and increases in bare ground, erosion, and root exposure. Thus, sites with dense tree canopies appeared to be more susceptible to damage. Although the relationship was less consistent, it also appeared that damage was particularly severe on infertile sites with thin, dry soils. The only variable that increased to any great extent with amount of use was percent bare ground. Other relationships were noted, but their meaning was often hard to interpret.

108. Ripley, T. H.
1962. Tree and shrub response to recreation use. USDA For. Serv. Res. Note SE-171, 2 p. Southeast. For. Exp. Stn., Asheville, N.C.

This report briefly surveys the condition of trees and shrubs on developed camp and picnic sites in the southern Appalachian Mountains of Tennessee and North Carolina. Based on an index of disease infection, insect infestation, and decline, 27 species are ranked according to their ability to withstand recreational use. Conifers were more susceptible than hardwoods and the dense shade they cast induced greater site deterioration. Results should be applied carefully because the lack of controls makes it impossible to be certain that observed tree condition is a result of recreational use.

109. Rogova, T. V.
1976. Influence of trampling on vegetation of forest meadow and whortleberry-moss-pine forest cenoses. Sov. J. Ecol. 7:356-359.

The effects of experimental trampling on meadow and forest vegetation in the USSR are discussed. Damage was greater after 350 passes/week than after 15 passes/week, although this difference was much less significant in the meadow. Despite greater resistance to deterioration at low trampling levels, forest understory vegetation recovered much more slowly than meadow vegetation, regardless of trampling intensity. The study period lasted only 1 month, however, so that results should be applied with caution. Trampling frequency, at rates of either 50 passes per day or 175 passes on 2 days of every 7 (same total number of passes), had little effect on rate of deterioration, but recovery was faster where trampling was equally distributed in time. Morphological characteristics of resistant and susceptible plants are also discussed.

110. Root, J. D., and L. J. Knapik.
1972. Trail conditions along a portion of the Great Divide trail route, Alberta and British Columbia Rocky Mountains. Res. Counc. Alberta Rep. 72-5, 24 p. Edmonton, Alta.

This report includes a good discussion of major types of trail damage, how damage occurs, and how it can be avoided on a trail in the Canadian Rockies. Degree of damage was a function of trail slope and orientation, soil type, and ground water conditions. Erosion increased on steep trails, particularly where they went directly uphill. The greatest amount of erosion, however, was found on alluvial plains with only 2 to 5 degree slopes, an illustration of the importance of soil texture. Alluvial plains have a high silt composition, which is easily eroded by running water. Other problems occurred where trails were located below areas of ground water discharge, snowbanks, or in areas with wet soils. Recommendations on how to locate and design a trail to avoid these problems are included.

111. Rutherford, G. K., and D. C. Scott.
1979. The impact of recreational land use on soil chemistry in a provincial park. Park News 15:22-25.

Used and unused areas, both in forest and grassland, were compared in a study of developed campsites in Brown's Bay Provincial Park, Ont., Canada. Soils in campsites had less organic matter than controls, with this difference much more pronounced in forested areas. Campsite soils were less acidic, had higher chloride concentrations, and lower nitrate concentrations. Phosphate increased on campsites in grassland and

decreased on forested sites. Cation exchange capacity and magnesium, potassium, and sulfate concentrations did not change in any consistent manner. The authors conclude that these chemical changes result from changes in organic matter content which are more pronounced in forested areas.

112. Satchell, J. R., and P. R. Marren.

1976. The effects of recreation on the ecology of natural landscapes. Nat. Environ. Ser. 11, Counc. Eur., Strasbourg, France, 117 p.

This report summarizes European research on ecological impacts resulting from recreation. It describes methods of measurement and analysis and reviews what is known about impacts on the soils, vegetation, and fauna of the following ecosystems: coastal ecosystems, grasslands, montane ecosystems, heaths, woodlands, footpaths and roads, maquis and other Mediterranean vegetation types, and freshwater ecosystems. A discussion of alternative means of managing impacts and an extensive bibliography are also included. The conclusion that research in recreational ecology has been scanty and uncoordinated is supported by obvious information gaps in the review and the fact that research results are usually not comparable.

113. Schreiner, E. G.

1974. Vegetation dynamics and human trampling in three subalpine communities of Olympic National Park, Washington. M.S. thesis. Univ. Wash., Seattle. 150 p.

Three subalpine meadows were trampled at a rate of 100 walks/week for 1 week and 5 weeks. These two treatments were compared with a control site during the 5-week study period. As hypothesized, hemicrytophytes were generally more resistant than other life forms, although each life form was variable in its response to trampling. Lichens were particularly sensitive. The author suggests, however, that trampling resistance may be more a matter of leaf morphology than of bud location. (See Rees and Tivy [1978, reference *106*].) The response of individual species to trampling was also variable, apparently a result of differences in site factors and plant form. In all three meadow types, vegetation damage was much greater following 500 walks than following 100 walks. Data on change in cover and frequency by species are provided.

114. Schreiner, E. G.

1975. Investigative methods for the study of site response to human trampling. Unpubl. pap. presented at the Resour. Manage. Conf., U.S. Dep. Interior, Natl. Park. Serv., Pac. Northwest Reg., Seattle, Wash. 15 p.

This paper discusses the advantages and disadvantages of various research techniques. (Compare with Burden and Randerson [1972, reference *21*].) It also describes some measureable parameters for quantitative investigations and includes a bibliography. The author concludes that more emphasis should be given to long-term studies.

115. Schreiner, E. G., and B. B. Moorhead.

1976. Human impact studies in Olympic National Park. *In* Proc. Symp. on Terrestrial and Aquatic Ecol. Stud. of the Northwest. p. 59-66. East. Wash. State Coll., Cheney.

A measure of bare ground at campsites was related to percent coarse fraction in the surface soil, winter snow depth (using lichen height as an indicator), and canopy cover. Due to great variability both between and within groups of campsites, few significant patterns were found for the park as a whole. The strongest relationship showed that bare ground increased as canopy cover increased, when sites in close proximity to each other were compared. The authors conclude that the degree of heteorogeneity they found suggests that each area within the park must be managed individually.

116. Settergren, C. D.

1977. Impacts of river recreation use on streambank soils and vegetation — state-of-the-knowledge. *In* Proc. River Recreation Manage. and Res. Symp. p. 55-59. David W. Lime and Clyde A. Fasick, eds. USDA For. Serv. Gen. Tech Rep. NC-28. North Cent. For. Exp. Stn., St. Paul, Minn.

This is a brief summary of research approaches to the study of recreational impacts and some generalizations from the literature. It provides a good overview of recreational impacts on many types of areas, not just along rivers.

117. Settergren, C. D., and D. M. Cole.

1970. Recreation effects on soil and vegetation in the Missouri Ozarks. J. For. 68:231-233.

Paired plots, in used and unused areas, were examined to determine the effects of recreational use on the soils of three 18-year-old camping areas. On used areas, soils had more rock close to the surface (presumably reflecting a loss of finer particles by erosion), fewer roots in the upper 6 in (15 cm) of soil (where they are concentrated in unused areas), a lack of organic matter in the surface horizon, and increased bulk density. Although not enough data on moisture availability is presented to evaluate the results, the authors conclude that moisture, particularly at the surface, is a limiting factor on used sites. Consequences of these effects are noted and it is suggested that soils which are naturally droughty, such as those studied, should not be developed for recreational use.

118. Sharsmith, C. W.

1959. A report on the status, changes and ecology of backcountry meadows in Sequoia and Kings Canyon National Parks. Unpubl. rep., 122 p. U.S. Dep. Interior, Natl. Park Serv., Sequoia and Kings Canyon Natl. Parks, Three Rivers, Calif.

Backcountry meadows which received little grazing use at the time of the study were slowly improving, while heavily used areas were being invaded by lodgepole pine and false hellebore (*Veratrum*) and were eroding. Some of these invasions had advanced as much as 100 ft (30 m) in the last 10 to 12 years. At the time of the report, no meadows had suffered irreversible damage, but several were in need of immediate help. The method used was primarily a comparison of 1958 conditions with photographs taken in 1940. More recent analyses of the same meadows can be found in Sumner (1968, reference *181*) and Stanley and others (1979, reference *124*).

119. Singer, S. W.

1971. Vegetation response to single and repeated walking stresses in an alpine ecosystem. M.S. thesis. Rutgers Univ., New Brunswick, N.J. 69 p.

This experimental study compared the effects on vegetation of different trampling intensities and frequencies (weekly versus one-time trampling). An alpine meadow in Mt. Rainier National Park was trampled weekly, at various intensities up to 150 tramples/week, for 8 weeks. In a second experiment the same meadow was trampled once at various intensities up to 150 tramples. By the end of 8 weeks, vegetation subjected to 75 to 150 tramples/week was significantly more degraded than

vegetation trampled 9 to 45 times/week. There was, however, no statistical difference in percent cover loss between areas trampled 9 and 45 times/week, and, in terms of cover loss, the plots which received the lowest trampling intensity were more similar to the plots receiving the most trampling than to the control plots. The same number of walks dispersed over time produced more damage than when that number of walks was concentrated in time. As with many of the other conclusions, however, this is based on just one example and should be treated as an hypothesis. This thesis is a good example of the type of data that needs to be collected at more sites and over longer periods of time if vegetation response is to be related to use characteristics.

120. Slatter, R. J.

1978. Ecological effects of trampling on sand dune vegetation. J. Biol. Educ. 12:89-96.

Transects oriented perpendicular to paths were utilized to document decreases in plant height, changes in species composition, and increases in bulk density along the paths. Monocotyledons and species with a hemicryptophytic or therophytic growth form survived heavy trampling more frequently than other species. Substantiates most of the findings of other authors (see Liddle [1975, reference *80*]).

121. Speight, M. C. D.

1973. Outdoor recreation and its ecological effects: a bibliography and review. Discuss. Pap. in Conserv. 4, Univ. College, London. 35 p.

This paper is a valuable compilation of the literature and an intelligent, succinct review of the state-of-the-art. It includes an overview of the effects of recreation on soils, vegetation, and wildlife, and how this information can be applied to the management situation. A good introduction to the literature, particularly the author's evaluation of shortcomings and progress in the field.

122. Spiridinov, V. N.

1979. Change in species composition of the herbage in herb birch forest under the effect of recreational stress. Sov. J. Ecol. 9:377-379.

With increasing recreational stress, expressed as the area of compacted soil surface, species richness decreases and weedy invaders become more prominent in the understory. Many of these invaders (such as, *Poa pratensis, Phleum pratense, Polygonum aviculare*, and *Platago* spp.) are commonly found on recreational sites in North America as well.

123. Stankey, G. H., and D. W. Lime.

1973. Recreational carrying capacity: an annotated bibliography. USDA For. Serv. Gen. Tech. Rep. INT-3, 45 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.

This bibliography contains 208 references on the following dimensions of carrying capacity: documentation of the need for more recreation space, definition of recreational carrying capacity, biological investigations of carrying capacity, investigations of esthetic carrying capacity, and managing for carrying capacity.

124. Stanley, J. T., Jr., H. T. Harvey, and R. J. Hartesveldt.

1979. A report on the wilderness impact study: the effects of human recreational activities on wilderness ecosystems with special emphasis on Sierra Club wilderness outings in the Sierra Nevada. Outing Comm., Sierra Club San Francisco, Calif. 290 p.

This report includes research results reported in Palmer (1972, reference *102*), Palmer (1975, reference *255*), and Strand (1972, reference *126*). Another paper by Strand on recovery of meadows following trampling by packstock showed that more recovery took place after 1 year in dry meadows than in very wet meadows. A paper by Palmer on revegetating multiple trails suggested the value of the following method: dig up and set aside the sod ridges between trails; break up the compacted soil and add sand to the trail tread until it reaches the level of the adjacent surface; then replant sod in the loosened soil. The report also contains papers on user characteristics, firewood production and use, waste disposal, and management recommendations. This is a useful collection of research results and opinions on wilderness management. The authors note numerous limitations to the studies, however, and many of the opinions are debatable.

125. Stelmock, J. J., and F. C. Dean.

1979. Vegetation trampling effects analysis — 1975 plots, Mount McKinley National Park, Alaska. Unpubl. rep., 67 p. U.S. Dep. Interior, Natl. Park Serv., Mt. McKinley Natl. Park, Alaska.

Stem counts of vegetation in plots at varying distances from trails were utilized to measure trampling effects. Results were highly variable and difficult to interpret due to small quadrat size. Generally, vegetation cover and height, species richness, and the density of most species decreased within 1 m of the trail. The authors conclude that the sensitivity of plants to trampling is highly variable and dependent upon site-specific characteristics of the community. A brief photographic study of trail recovery is also included. The report is most valuable for its evaluation of possible sampling and analysis techniques.

126. Strand, S.

1972. Pack animal impact: progress report on pack animal impact on wilderness meadows. *In* Wilderness impact study report. p. 37-48. H. T. Harvey, R. J. Hartsveldt and J. T. Stanley, eds. Outing Comm., Sierra Club, San Francisco, Calif.

Preliminary results of a study of packstock impact in the Sierra Nevada. Most meadows are recovering from earlier heavy use by domestic livestock and packstock, but the rate and type of recovery is dependent upon the amount of continuing use. The most important site factor influencing amount of impact appears to be fragility of the substrate, primarily the moisture content of the soil. The difference in impact after 100 tramples by hikers and by horses was negligible in dry areas, but packstock caused much more damage in wet areas. The final report appears in Stanley and others (1979, reference *124*).

127. Strand, S.

1972. An investigation of the relationship of packstock to some aspects of meadow ecology for seven meadows in Kings Canyon National Park. M.A. thesis. Calif. State Univ., San Jose. 125 p.

This thesis is basically an expanded account of the results reported in reference 126. There is, however, a more complete discussion of general ecological consequences of packstock use which is of additional interest.

128. Streeter, D. T.

1971. The effects of public pressure on the vegetation of chalk downland at Box Hill, Surrey. *In* The scientific management of animal and plant communities for

conservation. p. 459-468. E. Duffey and A. S. Watt, eds. Blackwell Sci. Publ., Oxford, Eng.

Trampling resulted in changes in the species composition and nutrient status of the soil. Moderate trampling resulted in nutrient enrichment while heavy trampling led to nutrient impoverishment. Vigorous, trampling-resistant species, which often require fertile soils, can invade trampled areas which receive moderate amounts of trampling. To some extent, then, "use actually produces a sward that is better adapted to the visitor pressure to which it is subjected." Thus both trampling stress and subsequent changes in fertility contribute to shifts in species composition.

129. Sumner, L., and R. M. Leonard.

1947. Protecting mountain meadows. Sierra Club Bull. 32(5):53-69.

This paper briefly discusses how use by packstock is destroying mountain meadows in the Sierra Nevada. The most interesting part is a sequence of photographs illustrating meadows at various stages of deterioration.

130. Sutton, S. W.

1976. The impact of floaters on the Ozark National Scenic Riverways. M.S. thesis. Univ. Missouri, Columbia. 152 p.

Areas frequently visited by recreational floaters were studied. Places which received heavy use, during the 1-year observation period, had less ground cover, fewer plant species, less litter cover, more rock and bare soil, and higher bulk density than unused areas. Impacts were more pronounced on stable soils than on temporary gravel bar sites.

131. Tachibana, H.

1969. Vegetation changes of a moor in Mt. Hakkoda caused by human treading. Ecol. Rev. 17(3):177-188.

The author relates vegetational differences in a sphagnum moor on Mt. Hakkoda, Japan, to differences in trampling pressure. Differences in height of vegetation, species composition, and denudation of the peat layer were related to an inferred human impact gradient. Primarily of interest as a case study from Japan.

132. Thornburgh, D. A.

1962. An ecological study of the effect of man's recreational use at two subalpine sites in western Washington. M.S. thesis. Univ. California, Berkeley. 50 p.

An early attempt to document the effect of recreational use on soil and vegetation at two subalpine sites in the Cascade Mountains of Washington, one at Klapatche Park in Mt. Rainer National Park and one at Image Lake in the Glacier Peak Wilderness Area. Used areas, identified visually and with the aid of a soil penetrometer were compared with undisturbed areas which often had to be found in adjacent drainages. Therefore, results must be interpreted cautiously. Heath species, such as *Phyllodoce empetriformis*, one of the dominants in the area, were quite susceptible to trampling damage, while *Antennaria lanata* was relatively resistant. The transition from disturbed to undisturbed vegetation was most abrupt in the forested areas. Mostly site specific in value.

133. Thornburgh, D. A.

1970. Survey of recreational impact and management recommendations for the subalpine vegetation communities at Cascade Pass, North Cascades National Park. Unpubl. rep., 42 p. U.S. Dep. Natl. Park Serv., North Cascades Natl. Park, Wash.

This report provides an evaluation of the susceptibility of species and plant communities to disturbances associated with camping. *Carex nigricans* subalpine meadows were the most resistant to use while severe disturbance was characteristic of campsites in *Tsuga mertensiana-Abies amabilis* (mountain hemlock-silver fir) forests. No recovery was observed following the use of bark chips or burlap nets on disturbed sites. The author suggests cultivating the soil and sowing native seeds, as well as careful control of camping. (See Miller and Miller [1976, reference *247*].) This report is largely site specific in value.

134. Thornburgh, D. A.

1973. Survey of recreational impact and management recommendations for the subalpine vegetation at Easy Pass, North Cascades National Park. Unpubl. rep., 19 p. Natl. Park Serv., North Cascades Natl. Park, Wash.

This site-specific description of damage to subalpine vegetation offers some suggestions for minimizing potential damage to a relatively pristine area.

135. Trew, M. J.

1973. The effects and management of trampling on coastal sand dunes. J. Environ. Plan. Pollut. Control 1(4):38-49.

This paper provides some data relating soil and vegetation changes to amount of trampling on two dune areas in southern England. It is primarily a general discussion of factors to be considered in managing dune areas for recreation.

136. Trottier, G. C., and G. W. Scotter.

1973. A survey of backcountry use and the resulting impact near Lake Louise, Banff National Park. Unpubl. rep., 254 p. Can. Wildl. Serv., Edmonton, Alta.

Mostly of site-specific value, this report describes visitor use and resulting impacts in a predominantly day-use area. Visitor use was determined from trail registers and user preferences were assessed with a questionnaire. Trail problems are described and the impact of camping on meadows is discussed. A good example of an impact study that contains methods which might be usefully applied in other areas.

137. Trottier, G. C., and G. W. Scotter.

1975. Backcountry management studies, the Egypt Block, Banff National Park. Unpubl. rep., 178 p. Can. Wildl. Serv., Edmonton, Alta.

Visitor attitudes and recreational impacts were assessed in an area in the southern Canadian Rockies of Alberta. Although mostly site specific in value, the report provides a good discussion of trail problems and offers useful management suggestions. General conclusions include: (1) poor trail conditions usually resulted from inadequate trail design, location, and maintenance, rather than overuse; (2) the major exceptions to this were trails used by large horse parties; (3) trail deterioration problems were more esthetic than ecologic; and (4) impact problems were highly localized.

138. Van der Werf, S.

1970. Recreatie-invloeden in Meijendel. [Recreation influences in Meijendel — a dune valley north of the Hague.] Meded. LandbHoogesch. Wageningen 70-17:1-24. [In Dutch, English summary.]

Recreation impacts were assessed in an area of sand dunes. The vulnerability of different types of terrain and vegetation was assessed and mapped, along with the current amount

of disturbance. A good example of how to base management on a thorough assessment of the current situation and potential for damage.

139. Wall, G.

1977. Impacts of outdoor recreation on the environment. Counc. Plan. Libr. Exch. Bibliogr. 1363, 19 p. Monticello, Ill.

A bibliography (not annotated), containing 183 references on the ecological impacts of various dispersed recreational activities, such as snowmobiling and hiking. Theses and published literature, both from Europe and North America, are the primary sources. All references have been written in the English language.

140. Wall, G., and C. Wright.

1977. The environmental impact of outdoor recreation. Dep. Geogr. Publ. Ser. 11, 69 p. Univ. Waterloo, Ont.

A good, general introduction to the subject, which briefly summarizes classic research in the field. It includes discussions of impacts on geology, soil, vegetation, water quality, wildlife, and air. Important research gaps are also identified. The treatment of the subject is not as insightful or interpretive as the review by Speight (1973, reference *121*), but it provides a good, basic overview of recreational effects on the environment.

141. Ward, R. M., and R. C. Berg.

1973. Soil compaction and recreational use. Prof. Geogr. 25:369-372.

Brief discussion of a study of soil compaction in Waterloo Recreation Area, Mich. Soil compaction was measured with a pocket penetrometer along transects across trails and campgrounds. Mean penetration resistance in frequently trampled areas was approximately 16 times greater than that in adjacent unused areas. The highly localized nature of recreational impacts is emphasized.

142. Weaver, T., and D. Dale.

1978. Trampling effects of hikers, motorcycles and horses in meadows and forests. J. Appl. Ecol. 15:451-457.

Experimental trampling was applied by hikers, horses, and motorcycles to a *Festuca idahoensis-Poa pratensis* grassland and a *Pinus albicaulis* (whitebark pine)-*Vaccinium scoparium* forest in the Rocky Mountains of Montana. Bare ground, trail width, trail depth, and bulk density increased with increasing number of tramples, up to the maximum of 1,000 passes. This relationship was distinctly curvilinear, however, with the greatest change in these variables occurring at low levels of trampling. Trails deteriorated more rapidly on sloping sites (15°) than on level ground. Creation of bare ground occurred more rapidly on the forested site, while trail depth and compaction were greater on the stone-free meadow soils. This suggests greater vegetation damage in forest and greater erosion problems in meadows. Both hikers and horses caused more damage walking downhill than uphill and hikers caused significantly less damage than either horses or motorcycles. This paper is a good attempt to relate use characteristics to the immediate effects of this use.

143. Westhoff, V.

1967. The ecological impact of pedestrian, equestrian and vehicular traffic on vegetation. *In* Proc. Int. Union for the Conserv. of Nat. and Nat. Resou., New Ser. 7. p. 218-223.

This paper presents a general overview, briefly discussing both beneficial and harmful influences of traffic on vegetation. Many ecologically specialized and interesting species respond favorably to the steep environmental gradient which occurs perpendicular to a travel route. On the other hand, excessive traffic results in impoverishment of the vegetation and compaction of the soil.

144. Whitson, P. D.

1974. The impact of human use upon the Chisos Basin and adjacent lands. Natl. Park Serv. Sci. Monogr. Ser. 4, 92 p. Gov. Print. Off., Washington, D.C.

This survey of human impacts on the vegetation of a part of Big Bend National Park, Tex., provides detailed, mostly site-specific observations of changes associated with trails and campgrounds. It provides a good discussion of how horse impact differs from hiker impact. Management suggestions include a program for revegetation, eradication of introduced species, and tighter controls on concessions and recreational activities. The survey is valuable as one of few discussions of human impact in this geographic area.

145. Whittaker, P. L.

1978. Comparison of surface impact by hiking and horseback riding in the Great Smoky Mountains National Park. Manage. Rep. 24, 32 p. U.S. Dep. Interior, Natl. Park. Serv., Southeast. Reg.

This study employed experimental trampling at various use intensities to compare the impact of horses, hikers with lug soles, and hikers with soft soles. Study sites included a pasture, an unmaintained footpath, and maintained trails in a mesic and xeric environment. Despite the short study period (2-½ weeks) some interesting results included: type of shoe made relatively little difference, except heavy shoes caused more redistribution of leaf litter; trampling on trails **reduced** compaction, regardless of type of use, but horse traffic in pastures reduced compaction and foot traffic increased compaction; reduced compaction resulted from churning the soil into dust or mud, a process that increased the potential for severe erosion and that was much more pronounced with horse use; height of vegetation and depth of leaf litter were reduced by trampling, with most of the reduction occurring at the lowest trampling intensities and with horse use causing greater reductions; site differences explained more of the variability in amount of change than trampling intensity, except where heavy horse use caused severe damage; trails through mesic forests were more severely altered, particularly by horse use than trails through xeric forests; and horse use not only caused greater damage but the types of changes, such as increased erosion potential, were more damaging.

146. Willard, B. E., and J. W. Marr.

1970. Effects of human activities on alpine tundra ecosystems in Rocky Mountain National Park, Colorado. Biol. Conserv. 2:257-265.

Observations of human impact near parking lots attest to the considerable effect of concentrated trampling on tundra vegetation. Although low levels of trampling (less than five people every few days) caused no noticable damage, the authors concluded that trampling by hundreds of people could destroy tundra ecosystems in a matter of weeks. In one area, which had been used for 38 years, all of the vegetation was gone and the A horizon was eliminated over 95 percent of the area. Observations on the susceptability to trampling of various species, growth forms, and plant communities are included. Generally, moist sites were more highly damaged than dry sites. Graminoids were more resistant than cushion plants,

which were more resistant than lush herbs. A scale of visitor impacts is also included.

147. Willard, D. E.

1971. How many is too many? Detecting the evidence of over-use in State parks. Landscape Archit. 61(2):118-123.

This article touches very briefly on many subjects related to overcrowding and the ecological impacts of recreation. Much attention is focused on the lack of tree regeneration in the Texas campgrounds under discussion.

148. Young, R. A.

1978. Camping intensity effects on vegetative ground cover in Illinois campgrounds. J. Soil Water Conserv. 33:36-39.

Vegetative characteristics of campsites receiving light, moderate, and heavy use were compared to control plots. Light use resulted in significant increases in bare ground and percent monocotyledonous species in the ground cover, and decreases in the number of species present, amount of organic litter and shrub cover. Where use exceeded 33 days/year (moderate use) there were further increases in bare ground and decreases in the number of species, but no further changes in any of the other variables. No additional changes occurred as use increased beyond 50 days/season. No differences in overstory vegetation were noted between controls and campsites. The suggestion is that most of the vegetative changes on campsites occur at low-use levels and differences in condition resulting from use intensity differences become insignificant at high-use intensities.

149. Young, R. A., and A. R. Gilmore.

1976. Effects of various camping intensities on soil properties in Illinois campgrounds. Soil Sci. Soc. Am. J. 40:908-911.

Chemical and physical soil changes are described on the same campsites studied and reported on in Young (1978, reference *148*). Soil compaction (resistance to penetration) and pH increased with use, as did organic matter, a result which contrasts with findings from most other areas. Quantities of exchangeable calcium, potassium, phosphorus, sodium, and nitrogen also increased with use. Most of these changes occurred with only light use; beyond a use level of 34 days/season there were additional increases only in pH, calcium, and compaction. This is one of the few studies of chemical changes in the soil resulting from recreational use. The increases in organic matter and nutrient content with use intensity suggest that a compacted layer may "protect" the underlying soil from leaching.

IMPACT MANAGEMENT

(Also see reference numbers *5, 11, 14, 24, 32, 44, 53, 56, 58, 70, 71, 72, 79, 91, 100, 112, 115, 121, 123, 124, 133, 134, 135, 136, 137, 138, 144, 194, 195, 208, 226, 260, and 277.*)

150. Bainbridge, D. A.

1974. Trail management. Bull. Ecol. Soc. Am. 55(3):8-10.

This plea for more research related to trail management identifies research gaps that need to be filled. This is a good, brief introduction to what still needs to be learned about trail problems.

151. Bayfield, N. G.

1971. A simple method for detecting variations in walker pressure laterally across paths. J. Appl. Ecol. 8:533-535.

This paper describes the use of transects of fine wires projecting from the ground (trampleometer pins) for determining the lateral distribution of trampling across paths. This technique measures relative trampling pressure rather than absolute numbers of people. Two examples illustrate the much broader lateral extent of trampling along paths through open as opposed to wooded areas.

152. Bohart, C. V.

1968. Good recreation area design helps prevent site deterioration. J. Soil Water Conserv. 23:21-22.

This brief general discussion of the importance of facility design to recreation management includes a few examples that may be applicable to backcountry.

153. Butler, E. A., and D. M. Knudson.

1977. Recreational carrying capacity. Element 16 of the 1975-79 Ind. Outdoor Recreat. Plann. Program, Div. Outdoor Recreat., Ind. Dep. Nat. Resour., Indianapolis. 124 p.

A literature review and report of preliminary study results related to recreational carrying capacity in developed recreation areas in Indiana. The authors briefly discuss the concept of carrying capacity and review some of the more important studies. Results of a visitor survey and a very brief campsite impact study are included. The report contains some interesting data, but most of the value is in the literature review.

154. Cieslinski, T. J., and J. A. Wagar.

1970. Predicting the durability of forest recreation sites in northern Utah — preliminary results. USDA For. Serv. Res. Note INT-117, 7 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.

A configurated roller was used to simulate trampling on sites in a lodgepole pine and aspen forest. Amount of surviving vegetation after 132 passes administered over an 11-week period was used as the dependent variable in a multiple regression analysis. The most durable sites were on steep northeast slopes, at low elevations. These results, however, were based on the amount of vegetation left on the site, not the amount that was destroyed by trampling. Further, these results do not consider recovery and are highly site specific. The authors recognized this and their primary conclusions are concerned with the apparent value of the method.

155. Coleman, R. A.

1977. Simple techniques for monitoring footpath erosion in mountain areas of north-west England. Environ. Conserv. 4:145-148.

Monitoring erosion can help managers contain the deterioration of footpaths. Depending upon the time span involved and the required accuracy, several monitoring methods are possible. Long-term trends can be measured on aerial photographs. Short-term trends can be identified by taking vertical measurements from either a taut cord or wire, or from a rigid bar attached to fixed points on both sides of the footpath. Practical suggestions, sample results, and advantages and disadvantages of each method are provided.

156. Cordell, H. K.

1975. The literature of planning and managing intensively developed natural resource recreation sites. *In*

Southern States Recreation Res. Workshop. p. 273-302. USDA For. Serv. Southeast. For. Exp. Stn., Asheville, N.C.

A step-by-step process is outlined for planning and managing developed recreation sites. The information here might be used for backcountry areas if the appropriate constraints of site access and design are considered. A bibliography of 130 references is included with codes that show to which step in the process they apply.

157. Craig, W. S.
1977. Reducing impacts from river recreation users. *In* Proc. River Recreation Manage. Res. Symp. p. 155-162. USDA For. Serv. Gen. Tech. Rep. NC-28. North Cent. For. Exp. Stn., St. Paul, Minn.

This report briefly discusses methods of preventing impacts and rehabilitating campsites in dispersed use settings. The author advocates confining visitors to designated campsites unless use levels are very low. A discussion of possible site restoration practices is also included.

158. Dalle-Molle, J.
1977. Mt. Rainier's backcountry system — a highly restrictive example. *In* Proc. Idaho Trail Symp. p. 32-41. Univ. Idaho, Moscow.

This paper discusses Mt. Rainier's backcountry management policies, reasons for these policies, and what will be done in the future to improve upon them. The author cites as major policy areas, rationing and use dispersal, minimum impact education, behavior regulation, and site restoration. An interesting discussion of methods for reducing impact in a heavily used National Park.

159. Densmore, J., and N. P. Dahlstrand.
1965. Erosion control on recreation land. J. Soil Water Conserv. 20:261-262.

The authors, both soil scientists, provide a brief general discussion of how recreation managers should plan facilities in such a manner that erosion potential is minimized. They stress the need for adequate water disposal and maintenance of vegetative cover.

160. Epp, P. F.
1977. Guidelines for assessing soil limitations for trails in the Southern Canadian Rockies. M.S. thesis. Univ. Alberta, Edmonton. 164 p.

A good study of how differences in various soil parameters affect trail condition. Trail condition was assessed at sites where all soil parameters but one could be held constant. Trail condition was judged on the basis of trail width, depth, muddiness, dustiness, loose and embedded coarse fragments, and roots. The major problem with this study design is that interaction between variables was not evaluated except in an anecdotal manner, that is, the conclusions for each soil parameter only apply strictly to the single set of environmental conditions which were held constant. Nevertheless, a useful table of limitations is developed which includes texture, gravel content, cobble content, stoniness, rockiness, slope, wetness, and flooding. Such a table could be very useful in locating trails, as long as interactions between parameters are taken into account. This document is useful, as is, in areas in the Northern Rocky Mountains and the method developed could be successfully applied elsewhere.

161. Fay, S. C., S. K. Rice, and S. P. Berg.
1977. Guidelines for design and location of overnight backcountry facilities. Unpubl. rep., 23 p. USDA For. Serv. Northeast. For. and Exp. Stn., Broomall, Pa.

This report is a good, practical discussion of some factors to consider when locating and designing backcountry campsites. Locational factors include soil, topography, aspect, vegetation, and water supply. Design considerations include layout, access, privy facilities, vegetation, fireplaces, and permanent photo points. A simplified table summarizes the suitability of various soil and vegetation types for facility location, but, as the authors note, the interaction of these factors makes such a summary somewhat misleading. Nevertheless, it provides good ideas which the manager should consider.

162. Frissell, S. S.
1978. Judging recreation impacts on wilderness campsites. J. For. 76: 481-483.

A synopsis of campsite condition classes and management prescriptions, which are described in more detail in Frissell (1973, reference *44*).

163. Hamburg, S.
1976. Backcountry trails. *In* Backcountry management in the White Mountains of New Hampshire. p. 52-55. William R. Burch, Jr. and Roger W. Clark, eds. Sch. For. Environ. Stud. Work. Pap. 2, Yale Univ., New Haven, Conn.

The author presents his opinions about how to locate and maintain a trail system. He suggests moving most trails from ridges to valleys and gently sloping hills, in contrast to the recommendations of some other researchers, such as Landals and Knapik (1972, reference *70*). He also advocates attempting to maintain a vegetative cover on trails by introducing non-indigenous plants and applying fertilizers.

164. Hendee, J. C., R. N. Clark, M. L. Hogans, D. Wood, and R. W. Koch.
1976. Code-A-Site: a system for inventory of dispersed recreational sites in roaded areas, backcountry, and wilderness. USDA For. Serv. Res. Pap. PNW-209, 33 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

This paper provides a suggested format for recording data about recreational sites. The system provides an inventory of sites, their resources, recreational opportunities, facilities, and condition. This system, often in revised form, is being widely used by backcountry managers, suggesting that it is a valuable inventory system. (See Schreiner and Moorhead [1976, reference *115*].)

165. Hendee, J. C., G. H. Stankey, and R. C. Lucas.
1978. Wilderness management. USDA For. Serv. Misc. Publ. 1365, 381 p.

This is a textbook, on the principles of wilderness management, written by three social scientists working for the Forest Service. The book includes discussions of the history of the wilderness idea, the legal basis for wilderness, important aspects of wilderness that must be managed, and management approaches. Ecological impacts are treated very generally because of the comprehensive nature of the book. This work provides a good overview of the subject.

166. Huxley, T.

1970. Footpaths in the countryside. Countryside Comm., Scotland. 51 p.

Footpaths are divided into those that develop spontaneously with human use and those that are purposefully constructed. The author relates the development of "natural" footpaths to such factors as human anatomy and motivations. Physical changes on footpaths are described, particularly the elimination of most plant species on paths. In Great Britain, the most resistant plant species, those capable of providing some cover on footpaths, are confined to lower elevations and nonwooded areas. The author discusses in some detail agents which cause footpath erosion, such as water and splash erosion, treading, and creep. He also describes factors to be considered when developing new trails or maintaining existing trails.

167. James, G. A.

1974. Physical site management. *In* Outdoor recreation research: applying the results. p. 67-82. USDA For. Serv. Gen. Tech. Rep. NC-9. North Cent. For. Exp. Stn., St. Paul, Minn.

The author states his concern that managers are not utilizing available information on site management. He feels this is a result of the highly dispersed nature of the information and the fact that most studies are so site specific. Some generalizations from the literature are provided, but most of the article is an annotated reading list.

168. Kuss, F. R., and J. M. Morgan III.

1980. Estimating the physical carrying capacity of recreation areas: a rationale for application of the universal soil loss equation. J. Soil Water Conserv. 35:87-89.

This article proposes using the universal soil loss equation, with several term substitutions, to determine the amount of ground cover that must be maintained on a site in order to avoid "excessive" erosion. This equation is based upon rainfall regimen, inherent soil erodibility, slope conditions, and vegetative cover. While this approach offers some possibilities, it should be used with caution outside of the croplands east of the Rocky Mountains, in which the empirical relationships were developed.

169. Leonard, R. E., and A. M. Whitney.

1977. Trail transect: a method for documenting trail changes. USDA For. Serv. Res. Pap. NE-389, 8 p. Northeast. For. and Exp. Stn., Broomall, Pa.

The amount of trail erosion occurring over time can be determined by periodically measuring the cross-sectional area between the trail surface and a horizontal tape. As described, the method can only be used in forested areas and the transects must be subjectively located. Slight modifications of the technique could make it applicable to other situations. The authors take an easy-to-follow, cookbook approach.

170. Lesko, G. L.

1973. A preliminary site capability rating system for campground use in Alberta. North. For. Res. Cent. Inf. Rep. NOR-X-45, 16 p. Edmonton, Alta.

A tentative system, based on theory, for evaluating the relative ability of different areas to tolerate impacts associated with campsite use. Factors included in the system were: degree days above 42° F, mean annual water deficit, shrub cover, grass cover, depth of rooting, thickness of the Ah soil horizon, thickness of the LHF layers (forest floor), slope, total ground cover, soil texture, and drainage. Soil texture and drainage are considered to be the most important independent variables and are used as weighting factors. This type of system would be extremely valuable in making locational decisions. As the author notes, however, it is a preliminary system which could provide misleading results if applied generally. It has not been field tested.

171. Mackie, D. J.

1965. Site planning to reduce deterioration. Proc. Soc. Am. For. 1965: 33-34.

This paper provides a very brief discussion of how to locate and design trails and campsites, from the perspective of a superintendent of parks and recreation in Wisconsin. Although most applicable to developed recreation areas, some of the suggestions may be applicable in backcountry.

172. McEwen, D., and S. R. Tocher.

1976. Zone management: key to controlling recreational impact in developed campsites. J. For. 74:90-93.

Following a good review of the literature, the authors conclude that recreational impacts are inevitable and rapid. Consequently, site rotation is impractical. Instead managers are urged to take advantage of the tendency for use to concentrate and to confine most impact to "impact zones." By recognizing impact, intersite, and buffer zones and by applying different management techniques to each, the authors feel that campsite impacts can be controlled. Although written with developed campsites specifically in mind, this management strategy could also be applied to the backcountry situation, where impacts are also highly concentrated.

173. Miller, R. W.

1974. Guide for using horses in mountain country. Mont. Wilderness Assoc., Bozeman, Mont. 15 p.

This booklet contains many suggestions about how to reduce the impact of horses in the backcountry. Topics include: preparation for pack trips, selecting a campsite, care of stock in camp, safety, conservation, courtesy, and feed for the horses. One point the author emphasizes is that hobbling is an ecologically sound means of restraining horses, while picketing and staking can cause considerable ecological damage unless great care is used.

174. Montgomery, P. H., and F. C. Edminster.

1966. Use of soil surveys in planning for recreation. *In* Soil surveys and land use planning. p. 104-112. L. J. Bartelli, ed. Soil Sci. Soc. Am. and Am. Soc. Agron.

Soils vary in their ability to support different types of recreational developments. Some of the soil parameters which affect capability are wetness, flooding, slope, rockiness, stoniness, permeability, surface soil texture, and depth to bedrock. Tables of limitations for different types of recreation are provided along with a dicussion of how to use soils information when deciding where to locate facilities. This paper is of limited value to backcountry management, but it does present a potentially useful approach.

175. Parks Canada.

1977. Campground Manual. Eng. Archit. Br., Parks Canada, Ottawa.

This manual describes how to plan, design, construct, and maintain campgrounds. Most attention is given to developed, auto-camping facilities, but many of the suggestions can be applied to backcountry sites. The mapping procedures described are particularly useful. This manual is very practical and well illustrated.

176. Parks Canada.

1978. Trail Manual. Eng. Archit. Br., Parks Canada, Ottawa.

An informative, well-illustrative manual on how to plan, design, build, and maintain trails. The first section discusses factors to consider when planning and designing a trail. This includes functional and esthetic requirements, concern for protecting the environment, trail hardening and structures such as bridges, and campsite location and design. The second section details the planning and design process. Section three provides construction and maintenance guidelines, and section four discusses special considerations for particular trail types. This should be a useful guide.

177. Proudman, R. D.

1977. AMC field guide to trail building and maintenance. Appalachian Mt. Club. 193 p.

A practical handbook on how to design, build, and maintain trails, written by the Appalachian Mountain Club's trail supervisor. Chapter headings are: Designing Trails, Environmental Considerations in Trail Design, Trail Layout, Trail Clearing, Trail Marking, Guidelines for Trail Reconstructions, Erosion Control, Hardening Trails in Wet Areas, and Tools. This handbook is well written and illustrated.

178. Rinehart, R. P., C. C. Hardy, and H. G. Rosenau.

1978. Measuring trail conditions with stereo photography. J. For. 76: 501-503.

Stereo photographs can be used to measure the cross-sectional area of a trail. Periodic remeasurements reveal the amount of trail erosion that has occurred. The authors compare the advantages of this monitoring technique to field measurements, such as those described by Leonard and Whitney (1977, reference *169*).

179. Shaine, B.

1972. Trails in wilderness. The Wild Cascades, June-July. p. 12-24.

Presentation of the author's opinions about how to improve upon current wilderness trail policy. Examples of problem trails in wilderness areas in the Cascade Mountains of Washington are provided. He makes the following recommendations: be more careful about routing trunk trails; conduct more ecological research; restrict use if necessary; keep horses out of alpine meadows and off some trunk trails; restoration should be started; keep trails out of the remaining "true wilderness"; initiate a zoning system; and change policy from use dispersal to concentration and restriction of use.

180. Snyder, A. P.

1966. Wilderness management — a growing challenge. J. For. 64:441-446.

This early appeal for wilderness management contends that top management priorities should be improved trail construction and location and more intensive campsite development. This paper is mostly of historical value.

181. Sumner, L.

1968. A backcountry management evaluation, Sequoia and Kings Canyon National Parks. Unpubl. rep. Natl. Park Serv., Sequoia-Kings Canyon National Park, Calif.

This report reviews changes in meadow condition based on 30 years of observations by various researchers. In most places, the pattern was one of increasing degradation until corrective measures were taken in the early 1960's. These measures included complete prohibitions on grazing, limits on length of stay and number of stock, and seasonal restrictions. Improvement during the 1960's led the author to conclude that the stock problem had been solved and that it was time to look at the impact of backpackers.

182. Tocher, S. R., J. A. Wagar, and J. D. Hunt.

1965. Sound management prevents worn out recreation sites. Parks and Recreation 48(3):151-153.

This is a brief, general discussion of how to prevent excessive impacts on recreational sites. Topics include: interpretation and education, patrolling and law enforcement, distribution of users, rationing, zoning, site hardening, fertilization, irrigation, and site rotation. The authors provide only enough detail to suggest management possibilities.

183. Wagar, J. A.

1961. How to predict which vegetated areas will stand up best under "active" recreation. Am. Recreat. J. 1(7):20-21.

Multiple regression equations were generated following a simulated trampling study in a southeast Michigan recreation area. These equations relate vegetation conditions following trampling to site factors and suggest that durable sites are shaded and have a vegetation cover which is dense and contains a large percentage of grasses and woody vines. These results are highly site specific, although the technique may be useful.

184. Walker, R. I.

1968. Photography as an aid to wilderness resource inventory and analysis. M.S. thesis. Colo. State Univ., Fort Collins. 114 p.

This thesis describes methods of using photography to monitor site impacts. The techniques discussed are panoramic photographs, monoscopic photographs, and stereophotogrammetry. Although largely exploratory in nature, it provides technical information which the manager could apply in developing a photographic monitoring system. The panoramic and monoscopic photographs were judged to provide more consistent and accurate results than the stereophotographic techniques investigated.

REHABILITATION OF IMPACTS

(Also see reference numbers *7, 14, 20, 35, 40, 50, 51, 56, 57, 58, 61, 67, 71, 75, 78, 108, 112, 124, 125, 133, 144, 156, 157, 182, 286, and 293.*)

185. Ahlstrand, G. M.

1973. Microenvironment modification to favor seed germination in disturbed subalpine habitats, Mount Rainier National Park, Washington. Ph.D. diss. Wash. State Univ., Pullman. 68 p.

Seeds of four subalpine species collected in Mount Rainier National Park were germinated under laboratory conditions. Stratification reduced the time required for germination and increased the germination success of *Anemone occidentalis, Aster ledophyllus,* and *Festuca viridula*. Seeds of *Lupinus latifolius* germinated readily without stratification. Exposure to light for longer than 14 hours per day inhibited the germination of *Anemone occidentalis*. High temperatures of 111° F (44° C) reduced germination success of all species. Ballard (1972, reference *287*) has suggested that ground surface tempera-

tures of 120° F (49° C) could be lethal to seeds and seedlings. Field plots with treatments (tilled, tilled and peat mulch added, tilled and covered with plastic) and controls were established in disturbed sites at Tipsoo Lake and Sunrise. Seeds of an introduced grass, *Festuca ovina* var. *duriuscula* were used as a standard to test treatment effects on germination. Germination was best on a plot covered with plastic that received ground moisture throughout the season. Other plastic-covered plots did poorly because of high temperatures and/or low moisture levels. Moisture on these plots declined throughout the season because the plastic prevented entry of water from storms. The tilled and tilled and peat mulch added treatments were second best with about 62 to 65 percent germination. Similarity between these two treatments was attributed to loss of the peat mulch from erosion. Lack of moisture was considered the most important factor inhibiting germination under field conditions.

186. Alderfer, R. H., and F. G. Merkle.

1943. The comparative effects of surface application vs. incorporation of various mulching materials on structure, permeability, runoff, and other soil properties. Soil Sci. Soc. Am. Proc. 8:79-86.

This paper is one of the best available on the effects of different kinds of mulch on soil properties. Plots were subjected to artificial rain after 5 tons/acre (11 200 kg/ha) of the different mulches were applied to the surface or incorporated into the soil. Mulches included charcoal, manure, straw, oak leaves, peat, sawdust, pine needles, grass clippings, sand and gravel, glass wool, complete fertilizer (4-12-8), nitrate of soda, and muriate of potash. In general, mulch on the surface had a more beneficial effect than when it was incorporated into the soil because the surface application protected the soil from raindrop splash. No runoff occurred and moisture content was highest on plots treated surficially with manure, oak leaves, straw, sawdust, or pine needles. Except for manure, incorporation of mulch did not increase the infiltration rate after the soil was saturated. The surface treatment with peat was unsuccessful because the mulch was blown off. This problem with peat blowing or eroding from plots is also noted by Ahlstrand (1973, reference *185*). This paper demonstrates the benefits of placing an organic mulch on the soil surface to protect the soil from raindrops and continued erosion. It was interesting to note that even the inorganic mulches such as sand and gravel afforded some protection to the soil surface.

187. Aldon, E. F.

1978. Endomycorrhizae enhance shrub growth and survival on mine spoils. *In* The reclamation of disturbed arid lands. p. 174-179. R. A. Wright, ed. Univ. New Mexico Press, Albuquerque.

Fourteen important southwestern shrub species were found to form associations with endomycorrhizae under field conditions. *Atriplex canescens* plants inoculated in the greenhouse with *Glomus mosseae* exhibited significantly greater survival and growth after two growing seasons than noninoculated plants. A list of New Mexico plant species known to have mycorrhizal associations is included.

188. Aldon, E. F., D. Cable, and D. Scholl.

1977. Plastic drip irrigation systems for establishing vegetation on steep slopes in arid climates. *In* Proc. 7th Int. Agric. Plastics Cong. [San Diego, Calif.] p. 107-112.

A drip irrigation system using plastic pipes enhanced plant establishment on steep slopes in New Mexico. Three different systems, applying a total of 10 to 23.5 in (26 to 60 cm) of water over a 7-week period, were tested. Increases in plant density as well as erosion from increasing amounts of irrigation water were noted. Drip systems such as these might be temporarily connected to streams as water sources and used in backcountry areas.

189. Aldon, E. F., and H. W. Springfield.

1975. Using paraffin and polyethylene to harvest water for growing shrubs. *In* Proc. Water Harvesting Symp. [Phoenix, Ariz. March 1974]. p. 251-257.

Polyethylene plastic and paraffin were tested as means of artificially harvesting water for transplants. Each material was arranged over an area of 9 ft^2 (0.84 m^2) around a transplant to funnel water toward the stem. The two treatments were effective in harvesting water from small storms, capturing an additional 34 to 40 percent of precipitation when compared to controls. Paraffin was spread over the soil surface as granules or flakes at the rate of 0.5 lb/ft^2 (2 kg/m^2). Similar methods, employing degradable materials, could be suitable for backcountry areas where periodic watering of transplants is impractical.

190. Appel, A. J.

1950. Possible soil restoration on "overgrazed" recreational areas. J. For. 48:368.

The author suggests that approximately 2 in (5 cm) of sawdust be placed on campsites and rototilled in with a high nitrogen fertilizer during the off season. This idea has merit, but other evidence in this review suggests the need for additional treatments such as seeds or transplants.

191. Baumgartner, D. M., and R. Boyd, eds.

1976. Tree planting in the Inland Northwest. Wash. State Univ., Coop. Ext. Serv., Pullman, Wash. 311 p.

This is a conference proceedings containing papers on tree planting for Washington, Oregon, Idaho, Montana, and Wyoming. Titles include: "Biology of Planting," "Choosing Tree Species for Planting," "When to Plant," and "Proper Seed Sources — a Key to Planting Success." Some of the methods presented can be used in backcountry areas with modification.

192. Bayfield, N. G.

1979. Recovery of four montane heath communities on Cairngorm, Scotland, from disturbance by trampling. Biol. Conserv. 15:165-179.

Vegetation damage and recovery following trampling were monitored in four heath communities. A total of 0, 40, 80, 120, and 240 walks were administered, with vegetative parameters being measured after 3 months, 1, 2, and 8 years. The major conclusion was that such studies are difficult to design and interpret. Each individual species and plant community had a distinctive pattern of damage and recovery, with some species not showing any damage until 1 year after trampling. The community which suffered the most initial damage also exhibited the greatest recovery after 8 years. The author suggests that studies attempting to rate vegetation susceptibility to trampling need to be continued past the initial damage stage and should consider both delayed damage and the recovery of individual species as well as entire communities.

193. Beardsley, W. G., and R. B. Herrington.

1971. Economics and management implications of campground irrigation — a case study. USDA For. Serv. Res. Note INT-129, 8 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.

The cost of installation and maintenance of an irrigation system in the Point Campground of Idaho is described. (See

Herrington and Beardsley [1970, reference *226*] for details of revegation.) Cost of the irrigation system was $0.26 per visitor day in 1969, or $95 per campsite. The closure of the campground on Tuesday nights for irrigation was well received by visitors. Alternatives to closing the campground for watering and better design and construction of the sites to facilitate watering are discussed.

194. Beardsley, W. G., R. B. Herrington, and J. A. Wagar.
1974. Recreation site management: how to rehabilitate a heavily used campground without stopping visitor use. J. For. 72:279-281.

Ground cover vegetation was reestablished and maintained through intensive cultural treatment. Good campground layout and artificial surfacing of heavy-use areas were important to this success. Treatments included a control with grass seed only; water and seed; fertilizer and seed; and water, fertilizer, and seed. Introduced species *Poa pratensis, Festuca ovina* var. *duriuscula, Trifolium repens, Festuca rubra* var. *rhizonomous, Poa trivialis,* and the native *Agropyron saundersii* were seeded in varying amounts. Nitrogen, phospate (P_2O_5), and potassium were applied at 70 to 210 (78 to 235), 14 to 35 (16 to 39), and 7 to 17.5 (8 to 19) lb/acre (kg/ha), respectively. Water was applied by sprinklers at a minimum of 1 in (2.5 cm) per week during the summer. Treatments were continued for 4 years. Fertilizer quantities were determined from soil nutrient analyses. The campground was closed to visitors between 2 p.m. Tuesday and 8 a.m. Wednesday each week for watering. This time was chosen to avoid watering prior to a heavy use period. No complaints were received because another campground was available in the area. Percent of available growing space covered by plants increased from 10 to 80 percent over the 4-year period. The combination of fertilizer, seed, and water was the best treatment, with fertilizer and seed second best. Costs per campsite are given.

195. Beardsley, W. G., and J. A. Wagar.
1971. Vegetation management on a forested recreation site. J. For. 69:728-731.

Water, seed, and fertilizer were used in an attempt to revegetate a northern Utah campground in an aspen and conifer forest. Water was applied in July and August at ½ in (1.2 cm) per week for three seasons. Urea formaldehyde and superphosphate were applied at 120 and 40 lb/acre/year (134 and 49 kg/ha/year), respectively. Species included *Phleum pratense, Dactylis glomerata, Bromus inermis, Poa pratensis, Agropyron intermedium, A. trachycaulum, Alopecurus pratensis,* and *Trifolium* spp. Under aspen, treatments increased plant cover from less than 10 percent to over 60 percent. Under the coniferous cover, no treatment increased plant cover to more than 15 percent. In general, as canopy covered decreased, treatment effectiveness increased. The treatment failure under the coniferous canopy is to be expected with the species listed above. Pasture species such as these cannot be expected to do well in this situation. A different grass adapted to growth under a coniferous canopy, such as *Festuca rubra*, might have yielded better results.

196. Berg, W. A.
1974. Grasses and legumes for revegetation of disturbed subalpine areas. *In* Proc., Revegetation of High-Altitude Disturbed Lands Workshop. p. 32-35. W. A. Berg, J. A. Brown, and R. L. Cuany, eds. Environ. Resour. Cent. Inf. Ser. 10, Colo. State Univ., Fort Collins

This is a discussion of selected introduced and native grasses and legumes that either have proven useful for revegetation or show promise for special circumstances. A brief annotation about reproduction, habitat, and utility of each species is included.

197. Berg, W. A., J. A. Brown, and R. L. Cuany, eds.
1974. Proc., Revegetation of High-Altitude Disturbed Lands Workshop. Environ. Resour. Cent. Inf. Ser. 10, 88 p. Colo. State Univ., Fort Collins.

This is the first of three workshops dealing with revegetation at high elevations. (See also, Zuck and Brown [1976, reference *281*] and Kenny [1978, reference *236*].) Topics include plant breeding, erosion control, species suitability, soils and soil problems, seed mixture, and general cultural practices. Most of the papers give a good overview of the topic of concern. Disturbance types discussed were those caused by pipelines, ski area activities, mines, and highways.

198. Bliss, L. C., and R. W. Wein.
1972. Plant community responses to disturbances in the western Canadian Arctic. Can. J. Bot. 50:1097-1109.

This study examined the effects of disturbances on arctic vegetation in western Canada. The disturbances (oil exploration, fire, and bulldozers) are only partially applicable to backcountry and wilderness areas, but the processes of change and recovery are relevant. One of the major impacts was surface subsidence in areas of high ground ice content, a change that may also result from recreational use. Subsidence was caused by removal of plant cover and all or part of the 2- to 8-in (5- to 20-cm) peat layer. Following fire, surface subsidence occurred in areas of high ground ice content, with recovery of grasses and sedges fastest and mosses and lichens slowest. *Eriophorum vaginatum* seedlings were common during the first 2 years, but survival was low. *Calamagrostis canadensis* and *Arctagrostis latifolia* were pioneers. Where surface subsidence of 1.6 to 6.6 ft (0.5 to 2 m) occurred, some revegetation took place, but there was little indication that immediate reseeding could prevent subsidence from occurring. In dwarf shrub-heath dry meadows and low wet meadows, nitrogen (but not phosphorus) appeared strongly limiting to plant growth. Nitrogen and roots were restricted to the surface organic layers. Surface disturbances to this system, therefore, were thought to have far-reaching effects on plant productivity and growth. *Calamagrostis canadensis, Poa lanata,* and *Arctagrostis latifolia* were noted as pioneers in the MacKenzie River Delta area. *Festuca rubra* and *Descurainia* pioneered drier sites and *Arctophila fulva* and *Eriophorum angustifolium* pioneered wetter sites. In seeding experiments, establishment was better on peats, but sustained growth was better on mineral soil, provided the peats and the mineral soils were kept moist. Fertilizer at 112 lb/acre (100 kg/ha) of nitrogen and phosphate, or phosphate alone, yielded better results than nitrogen alone, showing that phosphorus was limiting to the seedlings of species used. *Festuca rubra, Poa pratensis, P. compressa,* and *Phleum alpinum* did equally well on peats and mineral soil while *Alopecurus pratensis* grew better on mineral soil. Results indicated that seeds should be sown either in early spring as snow melts or in late fall before the first snow.

199. Brown, R. W., R. S. Johnston, B. Richardson, and E. E. Farmer.
1976. Rehabilitation of alpine disturbances: Beartooth

Plateau, Montana. Proc., Revegetation of High-altitude Disturbed Lands Workshop. p. 58-73. R. H. Zuck and L. F. Brown, eds. Environ. Resour. Cent. Inf. Ser. 21, Colo. State Univ., Fort Collins.

This paper describes research on methods of rehabilitating mining and highway disturbances in the alpine zone of the Beartooth Plateau, Mont. Results from seeding experiments showed that native species were more successful than introduced species, that fertilizer applications (15-40-5) at 100 lb/acre (111 kg/ha) were essential to plant establishment, and that additions of organic matter in the forms of peat moss at 2,000 lb/ha (2 240 kg/ha), steer manure at 4,000 lb/acre (4 480 kg/ha), or topsoil enhanced the rate of stand establishment. Fall seeding was recommended to ensure adequate moisture for germination and winter cold treatments for native species. Successfully seeded species included: *Deschampsia caespitosa, Alopecurus pratensis, Poa alpina, P. pratensis, Phleum alpinum, P. pratense, Dactylis glomerata, Trisetum spicatum, Bromus inermis, Carex paysonis, Agropyron intermedium, A. scribneri, A. trachycaulum,* and *Festuca arundinacea*. Seeds of native species were collected by hand. Transplanting experiments were 100 percent successful with some of the above species and with *Antennaria lanata, Lupinus argenteus, Sibbaldia procumbens,* and *Phyllodoce empetriformis*. Segments of turf that had slid down road cuts were employed for transplanting. This was considered the best method because survival rates were higher and because the transplants produced seed in 1 year. Plants were moved only when dormant. It was suggested that transplanting is particularly suitable for small areas of disturbance (such as backcountry campsites). Large-scale nursery production of native grasses in plastic tubes also appeared feasible. Most of the native colonizing species in the area were grasses and sedges. *Epilobium alpinum* and *Senecio* spp. were exceptions. These last colonized more mesic sites where pH was above 5.0.

200. Brown, R. W., R. S. Johnston, and D. A. Johnson.
1978. Rehabilitation of alpine tundra disturbances. J. Soil Water Conserv. 33:154-160.

This paper discusses the continuation of work on the rehabilitation of alpine disturbances described in Brown and others (1976, reference *199*). Most important is a table of plant species found to be successful for revegetation. The authors summarized their own work and added information available in the literature to compile the list.

201. Campbell, S. E., and G. W. Scotter.
1975. Subalpine revegetation and disturbance studies, Mount Revelstoke National Park. Unpubl. rep., 99 p. Can. Wildl. Serv., Edmonton, Alta.

Provides results of transplant trials using *Luetkea pectinata* and a reexamination of areas experimentally trampled 1 year previously and reported in Landals and Scotter (1974, reference *72*). Remeasurement of the trampling plots showed that the plant community which was destroyed most rapidly by trampling, the *Valeriana sitchensis* community, was also the community that recovered most rapidly; when both deterioration and recovery were considered, the most fragile communities were those dominated by the woody species, *Vaccinium membranaceum* and *Cassiope mertensiana*; the least fragile community was *Carex nigricans*; and there was little difference between the effects of one-time trampling and weekly trampling. Experiments with transplanting *Luetkea pectinata* used various treatments with and without water, fertilizer (8-4-4), and different sized plugs. The only significant differences noted over the 6-week observation period were that watering increased survival on dry, exposed sites and that larger plug sizes (15 to 20 cm^2) increased survival rates slightly. Fertilizer had no effect on survival. A limited experiment also suggested the following as possible species for transplanting: *Anemone occidentalis, Antennaria lanata, Arnica mollis, Carex spectabilis, Castilleja rhexifolia, Juncus drummondii, Luzula glabrata,* and *Valeriana sitchensis*.

202. Cleary, B. D., R. D. Greaves, and R. K. Hermann, eds.
1978. Regenerating Oregon's forests. Oreg. State Univ. Press, Corvallis. 287 p.

This is a handbook for forest regeneration in Oregon. Many of the principles and methods apply to rehabilitation in general. Chapters include: "Seed Source Selection and Genetics," "Site Preparation," "Seedlings," "Ecological Principles," and "Competing Vegetation."

203. Cook, C. W., R. M. Hyde, and P. L. Sims.
1974. Guidelines for revegetation and stabilization of surface mined areas in the western United States. Range Sci. Dep., Sci. Ser. 16, 73 p. Colo. State Univ., Fort Collins.

This book could serve as a general introduction and guide to rehabilitation by seeding. The mechanized methods described here are not appropriate for backcountry or wilderness areas, but the principles apply. Specific treatments and recommendations are made for the following: Northern Great Plains; desert vegetation; subalpine and alpine vegetation; and sagebrush, juniper, ponderosa pine, mountain brush, and aspen communities. Mulches, season of planting, soil preparation, fertilizers, topsoil, and weed control are discussed. The emphasis is on facilitating reclamation by native species.

204. Cordell, H. K., and G. A. James.
1971. Supplementing vegetation on southern Appalachian recreation sites with small trees and shrubs. J. Soil Water Conserv. 26:235-238.

Tree and shrub seedlings less than 24 in (61 cm) tall were planted prior to construction in a developed campground in the southern Appalachian Mountains in order to test the suitability of supplementing existing vegetation with planted stock. In general, survival was low because of damage from construction activities and competition from native plants. Mortality was correlated with overstory canopy in the sense that light-loving species did poorly under dense canopy and a 40 percent overstory cover reduction was associated with the greatest survival. Recreational use did not seem to have an effect on survival. Planting stock was obtained from a commercial nursery and included the following locally native species: *Rhododendron maximum, Kalmia latifolia, Leucothoe catesbaei, Rhododendron calendulaceum, Cornus stolonifera, C. florida, Cercis canadensis, Oxydendrum arboreum, Ilex opaca, Tsuga canadensis,* and *Diospyros virginiana*.

205. Cordell, H. K., G. A. James, and G. L. Tyre.
1974. Grass establishment on developed recreation sites. J. Soil Water Conserv. 29:268-271.

This study tested methods of obtaining a grass turf on campsites before they were opened for public use in Cherokee National Forest, Tenn. Treatments included staggered campground opening dates (1, 2, and 4 years after seeding); overstory canopy reductions of 10, 40, and 70 percent; and seeding with three species of grass, *Festuca rubra* var. *heterophylla, F. arundinacea* var. K31, and *Poa pratensis*. Fertilizer (15-15-15)

was applied to all sites at about 75 lb/acre (84 kg/ha) at the start of the study. The major findings were: no benefit was obtained from waiting to open the campgrounds for more than 1 year after seeding and dense overstory canopy severely limited establishment of seeded grasses and native colonizing species. The authors thought that a turf would have been established successfully if 46 lb/acre (15 kg/ha) of a 12-4-8 fertilizer had been applied both fall and spring along with repeated mowing to reduce competition from other species.

206. Cordell, H. K., and D. R. Talhelm.

1969. Planting grass appears impractical for improving deteriorated recreation sites. USDA For. Serv. Res. Note SE-105, 2 p. Southeast. For. Exp. Stn., Asheville, N.C.

Seeds of *Agrostis palustris, Zoysia japonica, Festuca elatior* var. *arundinacea, Cynodon dactylon, Festuca ovina* var. *duriuscula, F. Rubra, Poa pratensis,* and *Agrostis tenuis* were planted in campgrounds of National Forests in Georgia and Tennessee. Seeding was completed in September and survival was evaluated in spring, summer, and fall of the following year. Initial establishment was good, but survival was negligible except in protected areas and fenced control plots. This study provides an example of why site design; management methods, such as "impact pads" around heavy use areas; and perhaps fertilizers and water are needed to enhance success.

207. Czapowskyj, M. M.

1976. Annotated bibliography on the ecology and reclamation of drastically disturbed areas. USDA For. Serv. Gen. Tech. Rep. NE-21, 98 p. Northeast. For. and Exp. Stn., Broomall, Pa.

This bibliography includes 691 citations on mining effects and reclamation, mainly in coal regions. References are indexed by area, disturbance type, author, and subject. Approximately 100 references come under the heading "revegetation."

208. Dalle-Molle, J.

1977. Resource restoration. Unpubl. rep., 19 p. U.S. Dep. Interior, Natl. Park Serv., Mount Rainier Natl. Park, Longmire, Wash.

This is an excellent review of trail and campsite restoration methods used in Mount Rainer National Park. Along with rehabilitation efforts, the most important factor in success was to reduce trampling at the sites. The best method of reducing trampling was determined by repeated observations of visitor-use patterns and by questioning visitors as to why they used a particular route and what alternatives they would accept. Specific rechannelling methods included: blocking areas with logs, rocks, limbs, dirt mounds, and transplanted trees or shrubs and marking snow-covered trails with wands or a light layer of soil. A corrected drainage problem on a trail was sometimes enough to keep people from damaged areas. Success was enhanced when an alternative to a closed route was provided. Transplants have been used successfully as long as plants were less than 18 in (46 cm) tall. The importance of a large root ball and water at the time of transplanting is stressed. Seeding with native species was successful, but no list is provided. Cuttings from *Sorbus* sp. were unsuccessful, but no root hormone was applied.

209. Dittberner, P. L., and G. Bryant.

1978. The use of the Plant Information Network (PIN) in high altitude revegetation. *In* Proc., Revegetation of High-altitude Disturbed Lands Workshop. p. 52-74. S. T. Kenny, ed. Environ. Resour. Cent., Inf. Ser. 28. Colo. State Univ., Fort Collins.

This is a description of a computer-based data bank of native and naturalized vascular plants in Colorado, Montana, and Wyoming. Information is organized by plant species and then five major categories: geographic, life cycle, biological, reproduction, and ecological and economic. A large quantity of information, such as suitability for revegetation and elevation, is included. Requests are made by specifying such desired characteristics as high revegetation potential, geographic limits, perennial, and elevation. A list of species fitting the request is returned. This appears to be a very useful tool for people working on revegetation in the Rocky Mountain Region.

210. Doran, C. W.

1952. Adaptability of plants for reseeding high mountain peaks in western Colorado. USDA For. Serv., Rocky Mt. For. and Range Exp. Stn., Res. Note 10, 2 p. Fort Collins, Colo.

More than 50 species of native and introduced grasses and legumes are rated in this paper for use in Colorado rangeland seeding. Plots of each species were sown above 9,000 feet and then rated on the basis of survival and vigor after a 5-year period. Several introduced grasses (*Poa pratensis, Agropyron repens, Alopecurus pratensis, Agropyron intermedium, Phleum pratensis,* and *Bromus inermis*) were rated excellent for general suitability.

211. Douglas, G. W.

1974. Revegetation studies at Cascade Pass. Unpubl. rep., 18 p. U.S. Dep. Interior, Natl. Park Serv., North Cascades Natl. Park, Sedro Woolley, Wash.

Transplanting experiments were conducted with *Luetkea pectinata* at a heavily used subalpine backcountry area in North Cascades National Park. This species was thought to be ideal for revegetation work because it reproduced rapidly with runners, had a widespread distribution, was a pioneer species, and grew on a variety of sites. Plugs (8.7 cm in diameter) were moved into disturbed areas from adjacent undisturbed sites. *Luetkea* cover declined the first year and then increased during the next 3 years of the study. Frost heaving and damage caused by mammals killed a large number of plants. Nutrient analysis of foliage suggested that lack of nutrients was not a factor in mortality. Individuals of *Deschampsia atropurpurea, Hieracium gracile,* and *Carex nigricans* that were in some of the *Luetkea* plugs exhibited vigorous growth. Other researchers at Cascade Pass (Miller and Miller [1978, reference *248*] have verified that *Luetkea* is a good species to use in revegetation. They have found, however, that larger plugs (15 cm) and plants started from cuttings give a higher survival rate.

212. Dudeck, A. E., N. P. Swanson, L. N. Mielke, and A. R. Dedrick.

1970. Mulches for grass establishment on fill slopes. Agron. J. 62:810-812.

The effects of 11 mulches on seedling establishment of *Bromus inermis* were tested for 2 different years on road slopes in Nebraska. Materials examined were: wood cellulose fiber, excelsior mat, jute netting, wood chips, prairie hay, fiberglass, and emulsifiable asphalt used by itself and as an anchor for excelsior, wood shavings, bark dust, and corn cobs. Only the jute netting and the excelsior mat treatments resulted in satisfactory seedling emergence. The jute net and excelsior mat were both stapled to the ground surface to prevent erosion underneath and movement of the mulch.

213. Dyrness, C. T.

1975. Grass-legume mixtures for erosion control along forest roads in western Oregon. J. Soil Water Conserv. 30:169-173.

Five different seed mixtures of introduced legumes and grasses were tested on road slopes in western Oregon. All plots received 4,000 lb/acre (4 480 kg/ha) of straw mulch and 400 lb/acre (448 kg/ha) of phosphate fertilizer (16-20-0). Legumes were intended to provide a continuing source of nitrogen to the soil so refertilization would not be required to maintain grass cover. Only one legume species (*Trifolium repens*) survived, however, and refertilization was necessary. Other results included: no plant establishment occurred on slopes receiving mulch and fertilizer alone; even a partial grass cover, established with some mixes, was significant in reducing erosion; and unvegetated control plots eroded for the duration of the study. Successful grass species were: *Lolium multiflorum, Agrostis tenuis,* and *Festuca rubra* var. *commutata*. Bunch-type grasses, such as *Festuca arundinacea* and *Dactylis glomerata,* survived as scattered individuals only. A method of measuring soil erosion using cables is described.

214. Ellison, L.

1949. Establishment of vegetation on depleted subalpine range as influenced by microenvironment. Ecol. Monogr. 19:95-121.

Results from permanent plots and experimental seeding were used to evaluate plant succession patterns under the influence of grazing on the Wasatch Plateau. Emphasis was placed on determining the causes for slow plant establishment in bare areas between existing clumps of vegetation. Studies on permanent plots showed that soil surfaces which were initially bare of perennial vegetation could persist in that condition for many years, and that once overgrazing caused these bare areas, erosion, lack of soil moisture, and soil instability tended to prevent plant establishment. This paper along with Brink (1964, reference *296*) and Brink and others (1967, reference *297*) demonstrate the importance of ameliorating site conditions in order to facilitate revegetation on some subalpine sites.

215. Ettershank, G. N., Z. Elkins, P. F. Santos, and others.

1978. The use of termites and other soil fauna to develop soils on strip mine spoils. USDA For. Serv. Res. Note RM-361, 4 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

This was a laboratory study that used soils from mine spoils to determine if termites could be successfully introduced to benefit soil. Results were varied; some parameters increased (calcium, magnesium, carbonate) and some decreased (percent organic matter, sodium, sulfate). The termites had a beneficial effect on soil structure changing it from blocky to granular. This is an innovative approach to soil rehabilitation that should be examined further.

216. Farmer, E. E., R. W. Brown, B. Z. Richardson, and P. E. Packer.

1974. Revegetation research on the Decker Coal Mine in southeastern Montana. USDA For. Serv. Res. Pap. INT-162, 12 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.

Topdressing of peat held in place by jute netting, fertilizer (15-40-5), several different seed mixtures, and irrigation were tested as means of revegetating a mine spoil in Montana. Soils were ripped to a depth of 10 in (25.4 cm) and harrowed until no large clods remained at the surface. Fertilizer, seed, and peat were applied at 300, 25.5, and 5,000 lb/acre, (336, 28.5, and 5,600 kg/ha), respectively. The combinations of fertilizer, irrigation, and mulch yielded the greatest dry matter production for all seed mixes. The introduced grasses did better than the native grasses in terms of dry matter, but the study period was only one season. Other studies (Farmer and others [1976, reference *217*] and Brown and others [1976, reference *199*]) suggest that native species may do better in the long run. Exact proportions for seed mixtures are provided.

217. Farmer, E. E., B. Z. Richardson, and R. W. Brown.

1976. Revegetation of acid mining wastes in central Idaho. USDA For. Serv. Res. Pap. INT-178, 17 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.

Acid mining wastes in central Idaho were given several treatments to help achieve revegetation. A combination of lime, mulch (peat covered with jute netting), an 18-46-0 fertilizer at 435 lb/acre (487 kg/ha), and 8 in (20 cm) of topsoil usually provided the most ground cover. The best seed mixture was thought to be a combination of native and introduced species, because the introduced species did well initially and the native species were expected to take over in time. *Achillea millefolium* was able to survive adverse soil conditions with or without supplemental irrigation. *Deschampsia caespitosa* did well on plots seeded with natives only. *Dactylis glomerata, Phleum pratense,* and *Bromus tectorum* dominated plots of introduced species only after 2 years while *Poa pratensis* was unsuccessful. A native species, *Agropyron spicatum,* germinated, but survival was poor. Detailed results on plant biomass, foliar nutrients and soil conditions are included.

218. Fay, S.

1975. Ground-cover vegetation management at backcountry recreation sites. USDA For. Serv. Res. Note NE-201, 5 p. Northeast. For. and Exp. Stn., Broomall, Pa.

This study tested fencing, fertilization, and liming as possible means of restoring vegetation in a backcountry camp area in the White Mountains, N.H. Fertilizer (5-10-5) and hydrated lime were applied at the rate of 1,000 lb/acre (1 120 kg/ha) each. The combination of all three treatments was most effective, but this resulted in only a 4 to 6 percent increase in vegetative cover after one season. This study was too short to give a good picture of recovery rates, but it shows the necessity of additional treatments such as seeding, transplanting, and tilling the soil.

219. Gates, D. H.

1962. Revegetation of high altitude barren slopes in northern Idaho. J. Range Manage., 15:314-318.

Fertilizer, seeds, and mulch in the form of hay were used as treatments in this study. Results are difficult to interpret, but hay with ripe seeds, mowed near the site, and then used as a mulch provided the best seedling establishment. Seed brought in from other geographic locations did poorly. This demonstrates the importance of using seed for revegetation from the same general area where it is to be used. Material collected from one region and then used in another is often not as well adapted as that collected in the immediate vicinity.

220. Gifford, G. F., D. D. Dwyer, and B. E. Norton.

1972. A bibliography of literature pertinent to mining reclamation in arid and semi-arid environs. Man and the Environment Program, Utah State Univ., Logan. 23 p.

The emphasis of this bibliography is on rehabilitation of mining disturbances such as oil field wastes and slag heaps. Sections on general revegetation, mulches, and road stabilization are included. The authors have provided 312 sources.

221. Gomm, F. B.

1962. Reseeding studies at a small high altitude park in southeastern Montana. Mont. Agric. Exp. Stn., Bozeman, Bull 568. 16 p.

Tests were conducted in a subalpine rangeland area to determine the best soil preparation, seeding method, and species to achieve plant establishment. Results showed the following: plant establishment was the same when seeds were broadcast and drilled, except on plots that were plowed and disked rather than disked only; fertilizer increased growth, but not emergence in a greenhouse study; as intensity of disking increased, existing vegetation decreased and seeded species increased; and *Agropyron trachycaulum, A. smithii, A. cristatum, Bromus carinatus, Dactylis glomerata,* and *Poa pratensis* were fairly successful, but *Alopecurus pratensis* and *Bromus inermis* showed the greatest promise for establishing plant cover.

222. Greller, A. M.

1974. Vegetation of roadcut slopes in the tundra of Rocky Mountain National Park, Colorado. Biol. Conserv. 6:84-93.

Eight roadcut slopes in the alpine tundra of Rocky Mountain National Park were examined. Forty to 50 years after denudation, plant coverage was about one-half that of controls in cushion plant communities. The most important pioneer species were bunchgrasses, particularly *Agropyron scribneri* on south-facing slopes and *Poa fendleriana* on north-facing or late-snow-covered slopes. The process of colonization started with slope stabilization by grasses and proceeded to the filling in of interstitial bare areas by mat forming and cushion plants. Areas remained bare until the surface was stabilized by grasses. Other notable colonizers were: *Trifolium dasyphyllum, Sedum lanceolatum, Festuca brachyphylla, Draba aurea, Poa glauca, Erysimum nivale, Artemisia arctica, Trisetum spicatum, Arenaria fendleri, A. obtusiloba, Cirsium scopulorum, Geum rossii, Luzula spicata, Mertensia viridis,* and *Androsace septentrionallis.* These native colonizers might be useful species in a revegetation program on similar sites.

223. Harrington, H. D.

1946. Results of a seeding experiment at high altitudes in the Rocky Mountain National Park. Ecology 27:375-377.

Plant survival was evaluated on an old roadbed 6 years after it had been seeded and transplanted. Native species which successfully established from seed were: *Phacelia sericea, Deschampsia caespitosa, Heracleum lanatum, Trisetum spicatum, Achillea millefolium* ssp. *lanulosa,* and *Phacelia heterophylla.* Transplants of *Phacelia sericea, Arctostaphylos uva-ursi,* and *Phleum alpinum* had poor success. These results tend to be supported by those of other investigations (for example, Brown and others [1976, reference *199*; 1978, reference *200*]).

224. Heede, B. H.

1978. Designing gully control systems for eroding watersheds. Environ. Manage. 2:509-522.

This work emphasizes identification of gully erosion types and their geomorphologic characteristics. In some cases, erosion could be controlled by establishing vegetation only; in other cases, check dams were required. Guidelines are presented that will aid in determining the appropriate check-dam height. Even though this paper deals with erosion problems that are not related to recreational use, the methods and concepts are probably applicable to backcountry trails with severe erosion.

225. Heidmann, L. J.

1976. Frost heaving of tree seedlings: a literature review of causes and possible control. USDA For. Serv. Gen. Tech. Rep. RM-21, 10 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

Mechanisms and occurrence of frost heaving are described in some detail. Natural seedlings less than 1-year old were found to be more susceptible to heaving than larger, transplanted stock. Silt soils were more prone to frost action than clay or sand soils. Several methods of reducing frost heaving were discussed: dispersing the soil with sodium phosphates that reduce pore size; waterproofing the soil to reduce the available water for freezing; using cementing agents to hold the soil together; applying salts that lower the freezing temperature of water in the soil; and changing the radiation balance through shade, mulch, or some type of soil coating. Of these methods, changing the radiation balance appears to be the most feasible for backcountry revegetation projects. Addition of 3,000 lb/acre (3 360 kg/ha) of wheat straw mulch, for example, greatly reduced the number of freeze-thaw cycles and subsequent heaving.

226. Herrington, R. B., and W. G. Beardsley.

1970. Improvement and maintenance of campground vegetation in central Idaho. USDA For. Serv. Res. Pap. INT-87, 9 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.

Water, fertilizer, and seed were applied as treatments to increase vegetation cover in a developed Idaho campground. Prior to treatment, roads, trails, and the area around picnic tables were surfaced with a gravel-asphalt mixture to help channel visitors and "harden" sites. The seed mixture was composed of equal parts by weight of *Festuca ovina* var. *duriuscula, Poa pratensis, Trifolium repens, Agropyron saundersii* and was applied at the rate of 40 lb/acre (45 kg/ha). Fertilizer was put on four times to total 315, 49, and 24.5 lb/acre (353, 55, and 27 kg/ha) of N, P_2O_5, and K, respectively. Water was applied from sprinklers at the rate of 1.1 to 2.6 in (2.8 to 6.6 cm) per week. After 2 years, the most effective treatment was a combination of seed, fertilizer, and water, which increased plant cover from 10 to 50 percent.

227. Hodder, R. L., and B. W. Sindelar.

1971. Tubelings — a new dryland planting technique for roadside stabilization and beautification. Mont. Agric. Exp. Stn., Res. Rep. 18, 19 p. Mont. State Univ., Bozeman. [From Steen and Berg 1975.]

Plants were grown in deep paper tubes reinforced by plastic mesh sleeves and then transplanted into auger holes. The procedure eliminated the need for irrigation during establishment and enhanced survival of several tree, shrub, and vine species on arid sites. This method sounds like it could be a useful technique, but long-term survival as influenced by the plastic mesh should be checked.

228. Horton, J. S.

1949. Trees and shrubs for erosion control in southern California Mountains. Calif. For. and Range Exp. Stn. and State Calif. Dep. Nat. Resour. 72 p.

This paper discusses species used to control erosion on

road slopes, stream channels, burned areas, landslip scars, and sparsely vegetated areas. On steep slopes, brush wattles were of primary importance in providing mechanical soil stabilization so that vegetative cover could be established. Wattles consisted of cut brush placed in trenches along slope contours. Brush was embedded at least 6 in (15 cm) deep in trenches not more than 5 ft (1.5 m) apart. Stakes driven at least 24 in (61 cm) deep, with 2 in (5 cm) exposed, were placed just below the brush. Water readily entered the soil at brush wattles and, therefore, reduced surface runoff and erosion. Temporary plant cover was established using cereal grains, such as wheat, winter rye, and barley. The grains were followed by tree and shrub planting and additional grass and legume seeds. A table of successful tree and shrub species and their appropriateness for deep or shallow soils and full or partial sun is included.

229. Hull, A. C., Jr.

1943. Hand collection and cleaning of seed of native forage plants. USDA For. Serv., Intermt. For. and Range Exp. Stn., Res. Pap. No. 4, 4 p. Ogden, Utah.

Several methods of collecting native seeds by hand are briefly described. These include: hand stripping, combing, cutting and threshing, and a reel collector. The author discusses in detail the use of two hand paddles covered with rubber matting, but little attention is given to seed cleaning.

230. Hull, A. C., Jr.

1974. Seedling emergence and survival from different seasons and rates of seeding mountain rangelands. J. Range Manage. 27:302-304.

An analysis of factors affecting emergence and survival of seeded grasses on a subalpine range in Idaho is presented in this study. More seedlings emerged with seeding rates of 25 lb/acre (28 kg/ha) then with 10 lb/acre (11.2 kg/ha). Maximum emergence and survival were obtained from June seedings followed closely by July and then November, October, September, and August seedings. Small seedlings were often killed by drought and frost. Species employed in the study were: *Agropyron intermedium, A. trachycaulum, Alopecurus pratensis, Bromus inermis,* and *Phleum pratense.*

231. Isaacson, J. A.

1973. Use of native species on exposed soil sites. Unpubl. rep., 6 p. USDA For. Serv., Coeur d'Alene Nursery, Coeur d'Alene, Idaho.

Native plant species have been germinated and grown at the Coeur d'Alene Nursery and then shipped to other areas for planting. This paper summarizes some of the advantages of using native species and lists quantities of plants produced in 1972. When collecting native seeds, one must know: where to obtain sufficient seed at the proper state of development, when seeds are ripe and for how long they can be collected, and how to collect seed economically. Most seed should be collected from well-ripened fruit, but *Sorbus scopulina, Cornus stolonifera,* and *Acer glabrum* seed must be collected from slightly green fruit to achieve best germination. Some plants, such as *Ceanothus,* have explosive seed dispersal mechanisms and must be watched closely to select the proper time for collection. Planting of nursery stock has been accomplished with an auger for larger, long-rooted seedlings and a mattock or similar tool for smaller individuals. Experiments with direct seeding showed: sowing rates greater than 20 lb/acre were not beneficial; follow up fertilization the next year was essential; native shrubs and forbs did poorly on severe, dry sites; smoothing road slopes after construction had a detrimental effect on seedling establishment; and, once a site had been established with grass cover, native shrubs and forbs could be planted. Native species grown in the nursery from seed are listed. Ammonium phosphate fertilizer (16-20-0) was recommended at 500 lb/acre (560 kg/ha), unless there is a danger of it leaching into water supplies. Under these conditions, 250 lb/acre (280 kg/ha) was suggested. Frequently in rehabilitation work, plants for transplanting are in short supply. One alternative as suggested by Miller and Miller (1976, reference *247,* 1978, reference *248*) is to take cuttings or seeds to a greenhouse for propagation and subsequent transport to the revegetation area. Another alternative is to send seeds to a nursery, such as the one at Coeur d'Alene, where the plants can be grown and then returned to the sender.

232. Johnson, L., and K. Van Cleve.

1976. Revegetation in arctic and subarctic North America: a literature review. Cold Regions Res. and Eng. Lab. 76-15, 32 p. Hanover, N.H.

This review presents a good overview of revegetation and rehabilitation practices and problems in the arctic. Topics include site preparation, native versus introduced species, plant succession, species selection, and results of work on several species that have been used in the region. Native species with good potential for rehabilitation include: *Poa glauca, Festuca rubra, Arctagrostis latifolia, Puccinellia borealis, Deschampsia caespitosa, D. beringensis,* and *Calamagrostis canadensis* from seed; *Eriophorum vaginatum* from transplants; and *Betula* spp. and *Picea* spp. from cuttings. It was pointed out that the success of seeding was dependent on individual site conditions.

233. Johnston, R. S., R. W. Brown, and J. Cravens.

1975. Acid mine rehabilitation problems at high elevations. *In* Watershed Manage. Symp. p. 66-79. ASCE Irrig. and Drain. Div., Logan, Utah.

This paper presents a synopsis of ecological problems and factors involved in acid mine rehabilitation, but no results are provided because work had just been started at the time the paper was presented. Factors thought to be limiting to plant establishment included high solar radiation, cool air temperature, wind erosion, frost disturbances, short growing seasons, nutrient deficiencies, toxic chemicals, acid soils, and lack of water. Results of similar studies are reported in Farmer and others (1976, reference *217*) and Brown and others (1976, reference *199*; 1978, reference *200*).

234. Jollif, G. D.

1969. Campground site-vegetation relationships. Ph.D. diss. Colo. State Univ., Fort Collins. 139 p.

Some potential revegetation techniques were tested in the most severely deteriorated parts of three campgrounds in Rocky Mountain National Park. Treatments included seeding with three introduced grass species (*Festuca arundinacea, Bromus inermis,* and *Agropyron intermedium*), watering, and fertilization with nitrogen (½ to 1 lb per 1,000 ft^2; 24.4 to 48.8 kg/ha). The combination of seeding and fertilization was highly effective; watering also increased yields under most conditions. The author emphasizes the need to manage each site as individually as possible.

235. Keane, P. A.

1977. Native species for soil conservation in the Alps-New South Wales. J. Soil Conserv. Serv., N.S.W. 33:200-217.

This paper discusses the suitability of some native species for revegetating eroded alpine areas in the Snowy Mountains of Australia. It provides a good example of the type of potentially valuable autecological information that can be collected by studying species which naturally colonize bare areas. Mat-forming plants are the most successful native colonizers. Suggested treatments for increasing survival rates are offered for each growth form discussed.

236. Kenny, S. T., ed.

1978. Proc., Revegetation of High-altitude Disturbed Lands Workshop. Environ. Resour. Cent. Inf. Ser. 28. Colo. State Univ., Fort Collins. 213 p.

This is a collection of papers dealing with revegetation methods and results at high elevations. Topics include: economic and political aspects of revegetation, rare and endangered species, methods of testing soil nutrient status, a plant information network, plant breeding, mycorrhizae, mulches for erosion control, construction methods to make revegetation easier, species for revegetation in Alaska, and mining disturbance projects. A few papers have been reviewed separately.

237. Kidd, W. J., Jr., and H. F. Haupt.

1968. Effects of seedbed treatment on grass establishment on logging roadbeds in central Idaho. USDA For. Serv. Res. Pap. INT-53, 9 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.

This paper presents the results of a reseeding study using scarification and mulch to establish grass cover on logging roadbeds in *Pinus ponderosa* forests of central Idaho. Scarification treatments resulted in significantly greater seedling establishment than occurred on controls, but only when seeding followed treatment. Loosening the soil to a depth of 12 in (31 cm) compared to 3 in (8 cm) gave only slightly better results. Mulching with a 1-in (2.5-cm) layer of wood chips had a depressing effect on seedling establishment, although this effect was lessened when fertilizer was also added. Fertilizer alone at the rate of 40 lb/acre (45 kg/ha) of nitrogen and phosphorous gave better results than any treatment using mulch. North-aspect roads and sites receiving partial shade from adjacent trees exhibited better seedling establishment than south-facing slopes or full-sun sites. *Bromus inermis, Agropyron intermedium,* and *A. cristatum,* had the highest overall establishment rates (16 to 22 percent survival) and were thought best suited to the conditions of the study area. *Poa bulbosa,* however, was the best species on southwest-facing slopes. *Secale cereale* achieved initial establishment, but disappeared within 2 years.

238. Klock, G. O.

1969. Use of a starter fertilizer for revegetation establishment. Northwest Sci. 43:38. [Abstract only.]

"A successful soil stabilization program to prevent erosion requires the establishment of a vigorous ground cover immediately following site disturbance. The proper use of a starter fertilizer to meet this requirement has been demonstrated in the laboratory and in field investigations on newly developed ski slopes near Wenatchee, Wash. *Agropyron cristatum* was planted in the greenhouse on unfertilized soil from the ski slopes. Seedlings emerged but did not develop once seed energy stores had been exhausted. In 56 days the same soil type, fertilized with a prescription prognosticated by soil chemical analyses, produced up to 1.72 tons/acre (3 853 kg/ha) of ovendry material. Field plots established on ski slopes in August of 1968 confirm the validity of the greenhouse diagnosis."

239. Klock, G. O.

1973. Mission Ridge — A case history of soil disturbance and revegetation of a winter sport development. USDA For. Serv. Res. Note PNW-199, 10 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Lolium perenne and a mixture of *Dactylis glomerata, Phleum pratense,* and *Festuca ovina* var. *duriuscula* were broadcast seeded in the center of a ski run at Mission Ridge, Wash. A starter fertilizer was applied at the rate of 100 lb/acre (112 kg/ha) each of nitrogen (urea), phosphorus (superphosphate), and potassium (muriate of potash). The surface was lightly harrowed to cover seed and to minimize fertilizer loss from volitilization. Plants were successfully established by fall and exhibited good growth the following year. Plots receiving no fertilizer were unsuccessful.

240. Klock, G. O., A. R. Tiedemann, and W. Lopushinsky.

1975. Seeding recommendations for disturbed mountain slopes in north central Washington. USDA For. Serv. Res. Note PNW-244, 8 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Several species of native and introduced grasses and legumes were seeded in different combinations on firelines in north-central Washington. A starter fertilizer (ammonium phosphate sulphate, 16-20-0-15) was applied at 300 lb/acre (336 kg/ha). In general, success decreased with increasing elevation, except for *Poa compressa* which did well at higher elevations. The starter fertilizer was essential for good seedling establishment. Seedling mortality at higher elevations was attributed to frost heaving, cold air, soil temperature, short growing season, and high solar radiation. The most successful species overall were the introduced species: *Dactylis glomerata, Phleum pratense, Lolium perenne, Bromus inermis,* and *Festuca arundinacea.* The authors note that while the use of native species is to be encouraged, their rate of spread is often slow and introduced species may be necessary to establish an initial cover. An extensive table of species cover after 1 and 2 years and of seeding rates is included.

241. McArthur, E. D., B. C. Giunta, and A. P. Plummer.

1974. Shrubs for restoration of depleted ranges and disturbed areas. Utah Sci. 34:28-33.

Shrubs are an important element of the vegetation over much of the arid portions of the West. They provide habitat for wildlife, forage for livestock, and help stabilize soil on disturbed habitats. Some species have a wide ecological tolerance and are particularly valuable for rehabilitation work. More than 30 species are listed in this paper along with the vegetation types where they occur and their suitability for soil stabilization and range restoration. Geographic range and ecological characteristics of the following native shrubs are discussed in some detail: *Cowania mexicana, Falugia paradoxa, Symphoricarpos oreophilus, Kochia prostrata,* and several species of *Artemisia, Atriplex, Chrysothamnus,* and *Purshia.*

242. McClelland, B. R.

1972. Logan Pass seeding experiment. Unpubl. rep., 5 p. U.S. Dep. Interior, Natl. Park Serv., Glacier Natl. Park, West Glacier, Mont.

A series of seeding experiments were conducted in disturbed areas at Logan Pass between 1969 and 1971. Best seed germination was achieved with *Phleum alpinum, Erythronium*

grandiflorum, Luzula glabrata, and *Deschampsia caespitosa.* Introduced species, *Phleum pratense, Thlaspi arvense,* and *Chenopodium album,* invaded some sites and were recommended for removal. Mortality of native species after germination was attributed to lack of moisture and soil erosion. See Hartley (1976, reference *50*) for subsequent observations.

243. McGinnies, W. J., D. F. Hervey, J. A. Downs, and A. C. Everson.
1963. A summary of range grass seeding trials in Colorado. Colo. State Univ., Fort Collins, Agric. Exp. Stn., Tech. Bull. 73, 81 p. [Abstract copied from Steen and Berg 1975, reference *269*.]

"A large number of native and introduced grasses were evaluated for their ability to establish and persist on particular range sites from plains uplands to high mountain grasslands. Species which provided initial establishment, but did not persist could be distinguished. Seed source and ecotype differences were observed. *Bromus inermis, Alopecurus pratensis, Agropyron trachycaulum, Festuca rubra, Phleum pratense, Festuca thurberi,* and *Poa pratensis* were recommended for reseeding."

244. Marchand, P., and E. Spencer
1977. Progress report: Franconia Ridge alpine revegetation study. Appalachian Mt. Club, Boston, Mass. 9 p.

A combination of seed traps, plots on abandoned trails, soil movement measurements, and soil and foliar nutrient analyses were used to determine the best methods and species for rehabilitation of the Appalachian Trail in White Mountain National Forest, N.H. Plants on plots receiving liquid fertilizer (23-19-17) had significantly greater nitrogen and potassium content, but phosphorus content was not affected by fertilization. The soil pH (3.1 to 4.0) was thought to be too low for phosphorus uptake. Native colonizing plants on abandoned trails included mosses, grasses, *Prenanthes* sp., *Arenaria groenlandica, Potentilla tridentata,* and *Juncus trifidus.* Seed traps showed that seed dispersal was limited; *Agrostis borealis* and *Arenaria groenlandica* were the only species collected. Soil movement of up to 0.8 in (2 cm) vertical displacement from frost action was recorded by mid-November. The multiple approaches of this study provide a good example of how ecologically oriented rehabilitation studies can be conducted.

245. Marchand, P., and E. Spencer.
1978. Progress report: Franconia Ridge alpine revegetation study. Appalachian Mt. Club, Boston, Mass. 9 p.

Most of this work describes seed germination, dissemination, and production for selected species along the Appalachian Trail in New Hampshire. *Arenaria groenlandica* and *Juncus trifidus* produced the most seeds and flowers of the four species examined. Only *A. groenlandica, J. trifidus,* and *Potentilla tridentata,* the most important colonizers of abandoned trails, germinated without pretreatment in the laboratory. *Diapensia lapponica, Scirpus caespitosus, Carex bigelowii,* and *Geum peckii* did not germinate. It was noted that seed of colonizing species collected in seed traps rarely traveled more than 1 m from the parent plant. The short travel distance of seeds described in this paper is a contributing factor to the slow recovery of some backcountry disturbed sites, and underscores the importance of adding transplants and seeds to sites where recovery is desired.

246. Megahan, W. F.
1974. Deep-rooted plants for erosion control on granitic road fills in the Idaho batholith. USDA For. Serv. Res. Pap. INT-161, 18 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.

This study was started in 1968 and continued through 1972 on road fills in central Idaho. *Pinus ponderosa* (ponderosa pine) was seeded or planted in spacing arrangements of 1.5 × 1.5 ft (0.46 × 0.46 m) or 2.5 × 2.5 ft (0.76 × 0.76 m). Treatments included 1 to 2 in (2.5 to 5.1 cm) of straw mulch held in place with erosion net (galvanized chicken wire), fertilizer (Treefeed Pellets, 28-5-0, 1 per tree), and no mulch or fertilizer. Erosion was measured from catchment trenches lined with plastic. Fertilizer increased planted tree growth an average of 95 percent over 3 years. Planted trees alone provided reductions in erosion from 32 to 51 percent. A grass seeded plot started with 17 plants/ft^2 (183 plants/m^2) and decreased to 1/ft^2 (11/m^2) at the end of the study period. It was noted that the grass seeded plot followed a pattern similar to other road fills the author had observed where initial establishment was fair to good, but cover decreased with time. A 3 to 4 ft (0.9 to 1.2 m) spacing was recommended for future pine plantings.

247. Miller, J. W., and M. M. Miller.
1976. Revegetation in the subalpine zone. Univ. Wash. Arbor. Bull. 39(4):12-16.

This summarizes 7 years of pioneering work on rehabilitation of campsites and trails at Cascade Pass in the subalpine zone of North Cascades National Park. Direct seeding experiments showed that this method was practical only on moist sites. The most successful species were *Carex nigricans* and *Carex spectabilis* followed by *Luetkea pectinata, Potentilla flabellifolia, Saxifraga ferruginea, Valeriana sitchensis,* and *Veratrum viride. Veratrum* required 2 years to germinate. *Arnica latifolia, Lupinus latifolius, Cirsium edula, Erigeron peregrinus* and *Mimulus lewisii* seedings were unsuccessful. Burlap netting laid on top of the plots aided in reducing erosion and maintaining soil moisture. It was necessary to dig the areas up to eliminate compaction. Transplanting was a useful technique, but obtaining material in the area was a problem because of the limited number of places to obtain vegetation without leaving unsightly scars. Clumps that were 5.9 in (15 cm) in diameter had a 97 percent survival rate compared to 50 percent survival with 3.4 in (8.7 cm) plugs. *Carex* spp., *Luetkea pectinata,* and *Potentilla flabellifolia* were successful. Propagation of cuttings and divisions collected near the site to be revegetated and taken to lower elevation nurseries was suggested as the method with the greatest promise. The most difficult problem was logistical since the plants had to be returned to the area in backpacks. *Carex nigricans, Cassiope mertensiana, Luetkea pectinata, Saxifraga ferruginea, Phyllodoce empetriformis, Tsuga mertensiana,* and *Sibbaldia procumbens* had 85 percent survival 2 years after being transplanted at the pass. In the greenhouse, cuttings and divisions were treated with Hormodin 3 (0.8 percent indolebutyric acid) or Rootone No. 10 (0.4 percent Alpha Napthyl acetamide), set in 1:1:1 sand-peat moss-perlite and placed under intermittent mist at 70° F (21° C) soil temperature. See Miller and Miller (1977, reference *249*) for more information on specific methods.

248. Miller, J. W., and M. M. Miller.
1978. Revegetation of impacted subalpine plant communities in North Cascades. Unpubl. rep., 18 p. U.S. Dep. Interior, Natl. Park Serv., North Cascades Natl. Park Complex, Sedro Woolley, Wash.

The revegetation history of Cascade Pass in North Cascades National Park is summarized in this report; some general

uidelines for backcountry revegetation are also included. See liller and Miller (1976, reference *247*) for most of the results of eeding and transplanting work in in this area. Two guidelines r reducing the impact of revegetation itself include the follow-ig advice: when transplanting, fill the holes where plants were emoved with soil or rocks to facilitate natural revegetation; and hen transplanting wear smooth-soled shoes to minimize tram-ling damage. Of the species worked with at Cascade Pass, *uetkea pectinata, Carex nigricans, C. spectabilis,* and *Sibbal-ia procumbens* had the greatest survival and growth. *Phleum lpinum,* which exhibited no seed dormancy, was successfully rown from seed in the greenhouse and returned to the pass for lanting. A useful table of criteria to determine whether or not a ite is suitable for on-site seeding with native species is pro-ided.

49. Miller, M. M., and J. W. Miller.
 1977. Suggested revegetation practices. Unpubl. rep., 13 p. U.S. Dep. Interior, Natl. Park Serv., North Cascades Natl. Park, Sedro Woolley, Wash.

This paper discusses species selection, transplanting, eeding, and greenhouse propagation methods. Procedures re described in sufficient detail for the work to be used as a ackcountry revegetation manual. Special problems including ire rings, shelter sites, trails, frost heaving, large shrubs, and revention of additional impact are addressed. This is probably he best paper available on how to rehabilitate backcountry ites damaged as a result of recreational use.

250. Milstein, G. P., and D. Milstein.
 1976. Collecting and cleaning of wildflower seed. *In* Proc., Revegetation of High-altitude Disturbed Lands Workshop, No. 2. p. 41-53. R. H. Zuck and L. F. Brown, eds. Environ. Resour. Cent. Inf. Ser. 21. Colo. State Univ., Fort Collins.

This is an excellent step-by-step guide for collecting wild-lower seeds. Information on germination, drying, and storage is also included. A list of species and their germination require-ments is included in the index.

251. Mitchell, W. W.
 1978. Development of plant materials for revegetation in Alaska. *In* Proc., Revegetation of High-altitude Disturbed Lands Workshop, No. 3. p. 101-115. S. T. Kenny, ed. Environ. Resour. Cent. Inf. Ser. 28, Colo. State Univ., Fort Collins.

Introduced and native grasses in use or having good potential for revegetation of disturbed sites in Alaska are discussed by species. Cold soils over permafrost and winter survival were noted as important limiting factors that must be overcome for successful revegetation projects. Some Alaska grasses have good potential, but the author indicates that more work is needed to find disease-resistant species or populations.

252. Monsen, S. B.
 1975. Selecting plants to rehabilitate disturbed areas. *In* Improved range plants. p. 76-90. R. S. Cambell and C. H. Herbel, eds. Range Symp. Ser. 1, Soc. Range Manage., Denver, Colo.

This is an overview of the different kinds of plants used to rehabilitate disturbed areas. Emphasis is placed on the fact that a wide variety of methods and species may be required to complete a rehabilitation project successfully. The author notes that a combination of grasses, forbs, and shrubs is best to improve forage on range sites, but that planting of shrubs has been discouraged in the past because both planting stock and knowledge of proper planting techniques were lacking. Recent advances in propagating native plants from seeds in nurseries, however, now make it feasible to use more native species, including shrubs (see Isaacson [1973, reference *231*]). A good method of native plant species selection is to use existing plant communities as guidelines. Areas with harsh growing conditions have furnished planting stock for treating severe disturbances. It is also noted that introduced species have proven useful in rehabilitation projects, especially for establishment of an initial plant cover. Native colonizing species that have been successfully transplanted or seeded include: *Penstemon fruticosa, Eriogonum umbellatum, Chrysopsis* spp., *Clematis ligusticifolia, Lonicera ciliosa, Ceanothus martinii, Fallugia paradoxa, Cowania mexicana, Purshia glandulosa, Ephedra viridis, Solidago canadensis, Penstemon* spp., and *Artemisia ludoviciana.* Native seral species that have been successful once established include: *Ceanothus velutinus, Prunus emarginata, Rosa woodsii,* and *Sambucus caerulea.*

253. Moorman, T., and F. B. Reeves.
 1979. The role of endomycorrhizae in revegetation practices in the semi-arid west. II. A bioassay to determine the effect of land disturbance on endomycorrhizal populations. Am. J. Bot. 66:14-18.

This is the second part of the study by Reeves and others (1979, reference *261*). *Zea mays* was planted on disturbed and undisturbed sites in Colorado and harvested after 30 days. Inoculum levels of *Glomus fasciculatus* were measured at that time. Two percent of the plants on disturbed soil were infected while 77 percent on the adjacent undisturbed soil were infected. It was suggested that the low levels of active mychorrhizae on the disturbed site will be an important ecological factor in subsequent succession.

254. Packer, P. E., and E. F. Aldon.
 1978. Revegetation techniques for dry regions. *In* Proc., Reclamation of Drastically Disturbed Lands. p. 425-450. F. W. Schaller and P. Sutton, eds. Am. Soc. Agron., Madison, Wis.

This is a good overview of revegetation practices and environmental factors in the northern Great Plains and arid Southwest. Soil amendments, mulches, fertilizers, seeding methods, planting methods, and species are discussed for each region. Recent advances in the technology of revegetation and continued management of revegetated areas are also discussed.

255. Palmer, R.
 1975. Progress report on trail revegetation studies. Unpubl. rep., 6 p. U.S. Dep. Interior, Natl. Park Serv., Yosemite Natl. Park, Calif.

Test plots, protected by steel fencing and barbed wire, were set up to evaluate rehabilitation success on eight parallel trail scars in Tuolomne Meadows, Yosemite National Park. Techniques tested included combinations of scarification, seeding with *Carex exserta,* burlap mulch, soil addition, sod plug transplanting (mostly *C. exserta*), rock fill, breaking up sod ridges between trails, adding them to the trail, and planting with plugs from the ridges. Observations after 2 years indicate the most effective method was digging perpendicular to the trails and using soil and plugs taken from the ridges between trails as fill.

256. Parsons, D. J., and S. H. DeBenedetti.
 1979. Wilderness protection in the High Sierra: effects

of a 15-year closure. *In* Proc. Conf. Sci. Res. in Natl. Parks. p. 1313-1318. R. M. Linn, ed. U.S. Dep. Interior, Natl. Park Serv., Trans. and Proc. Ser. 5. Gov. Print. Off., Wash., D.C.

After a 15-year closure, campsites that had received high visitor use at a subalpine lake were compared to campsites in a continually disturbed lake area and in an undisturbed control site. All areas had similar vegetation, with *Pinus contorta* (lodgepole pine) and *Pinus albicaulis* (whitebark pine) dominating the forest component. Measurements showed that after 15 years, fuel accumulation had not completely recovered, either because of insufficient time or illegal camping. Litter accumulation and soil resistance to penetration on closed sites were comparable to litter accumulation and soil resistance to penetration on controls. Tree mutilation was still evident, but regrowth was occurring. Social trails around the lake were still visible, although there had been some recolonization by *Deschampsia* spp., *Carex* spp., *Vaccinium nivictum, Kalmia polifolia,* and *Aster alpigenus.* This slow recovery of social trails suggests that some means of assisting recovery should be considered.

257. Peterson, E. B., and N. M. Peterson.
1977. Revegetation information applicable to mining sites in northern Canada. Environ. Stud. 3, 405 p. Dep. Indian North. Aff., Ottawa, Can.

An excellent bibliography with detailed annotations. Although it is specifically concerned with northern Canada, many of the papers discuss material that is applicable elsewhere.

258. Plummer, A. P.
1976. Shrubs for the subalpine zone of the Wasatch Plateau. *In* Proc., Revegetation of High-altitude Disturbed Lands Workshop, No. 2. p. 33-40. R. H. Zuck and L. F. Brown, eds. Environ. Resour. Cent. Ser. 21, Colo. State Univ., Fort Collins.

Twenty shrub species are rated for their suitability in subalpine revegetation. Ratings were based on seeding success, transplanting success, rate of spread, growth, and adaptation to disturbance. It was suggested that direct seeding be attempted in the fall to overcome the inherent dormancy in most shrub seeds. Transplanting in the spring was thought to be best since sufficient reliable moisture is available at this time. It was noted that successful fall transplanting required both moist soil and an insultating snow cover over winter. Apparently neither is reliable in this region. Other studies show that time of transplanting varies between regions and that the best time should be verified with local growers and foresters. Mechanical seed harvesting methods appeared feasible for some shrubs, but most species were thought to require hand collection. Development of seed orchards at lower elevations was suggested as a possible alternative. Species with particular promise as ground cover and forage were: *Symphoricarpos oreophilus, Chrysothamnus viscidiflorus, Sambucus racemosa,* and two varieties of *Artemisia tridentata.*

259. Plummer, A. P., D. R. Christensen, and S. B. Monsen.
1968. Restoring big game range in Utah. Utah State Dep. Natl. Resour., Div. Fish Game Publ. 68-3, 183 p.

This work summarizes results of research to improve range productivity in Utah. The suitability of more than 400 plant species is reported here. Planting techniques and restoratio principles are discussed in some detail. A useful list of adaptec species for each of 12 vegetation types, ranging from pinyon-juniper forests to subalpine herblands, along with ecological characteristics of major species and viability of stored seeds, is included. This is a good reference for rehabilitation in Utah.

260. Ranz, B.
1979. Closing wilderness campsites: visitor use problems and ecological recovery in the Selway-Bitterroot Wilderness, Montana. M.S. thesis. Univ. Mont., Missoula. 125 p.

This study reports on the effects of closing campsites around a popular midelevation (5,865 ft) lake in the Selway-Bitterroot Wilderness, Mont. After 5 years of closure, interesting findings include: closed campsites had 14.7 percent more cover than open campsites; recovery rates suggest that 16 years would be required for return to a "natural" amount of vegetative cover (this is an average figure and assumes a constant rate of recovery); there was no difference in the organic litter cover between open and closed sites, although campsites had 29 percent less litter cover than controls; graminoids, in particular increased on closed campsites, so that graminoid cover on closed campsites was 50 percent greater than on control plots most of the prominent increasers on closed campsites were weedy Eurasian species (such as *Poa annua* and *Trifolium repens*); and seven new campsites developed on the lake following the closure of seven campsites. This suggests that vegetation at this location will recover, although it will apparently take 10 to 20 years for a return to "natural" cover values Recovery of the organic litter layer and original species composition would take much longer. Moreover, with the development of new campsites, the total area disturbed by camping increased greatly. This illustrates some of the reasons why campsite rest-rotation is usually impractical (see Merriam and others [1973, reference *98*]). If selected campsites are closed alternative sites must be available.

261. Reeves, F. B., D. Wagner, T. Moorman, and J. Kiel.
1979. The role of endomycorrhizae in revegetation practices in the semi-arid west. I. A comparison of incidence of mycorrhizae in severely disturbed vs natural environments. Am. J. Bot. 66:6-13.

This study compared the incidence of plant species associated with mycorrhizae on an old roadbed with that on an undisturbed area in Colorado sagebrush country. More than 99 percent of the plant cover on the undisturbed community was mycorrhizal while less than 1 percent was mycorrhizal on the old roadbed. The authors cite evidence indicating that many colonizing species are not associated with mycorrhizae while later successional species are. A list of nonmycorrhizal species and genera is included. It is increasingly evident from studies such as this one that mycorrhizae should be of concern to people involved in revegetation. Severely disturbed sites often lack mycorrhizae because mycorrhizal plant species will not survive when transplanted if the soils or plants have not been inoculated (see Zak [1975, reference *348*]). This would be a most important consideration for people trying to recreate a plant community at an advanced stage of succession. Little is known about the mycorrhizal associations of species other than commercial tree species; so obtaining appropriate material for inoculation is not possible at this time.

262. Ripley, T. H.
1965. Rehabilitation of forest recreation sites. Proc Soc. Am. For. 61:35-36.

This is a general discussion of how to rehabilitate overused recreation sites. Procedures outlined are as follows: determine if the site should be relocated to a more durable place; ensure that all drainage problems have been corrected; establish hardened travel routes that can take heavy use without further damage to vegetation and soils; use shrubs and trees to help divert and channel visitor use onto hardened routes; establish a grass rather than forb turf in the immediate vicinity of such sites as picnic tables; select several tree species to maintain some overstory cover; and provide for continued maintenance of vegetation.

263. Schilling, C. L.

1977. Transplanting sapling-size trees for campground development. J. For. 75:132-135.

A "Tree Spade," a motorized device, was used to transplant trees from 1 to 4 in (2.5 to 10 cm) d.b.h. and 15 to 25 ft (4.6 to 7.6 m) in height. Survival rates are presented for 29 deciduous tree species that were planted in a Kentucky campground. The overall survival rate was 92 percent after 2 years. Saplings are almost impossible to transplant under backcountry conditions with tool limitations, but would be quite useful for rearranging visitor use patterns if a suitable method of transplanting them could be found. Use of the Tree Spade is not appropriate in backcountry areas, but trees could be dug up with the machine in other locations and transported to the backcountry.

264. Schreiner, E.

1977. Evaluation of the 1976 plant restoration project at Lake Constance after one year. Unpubl. rep., 6 p. U.S. Dep. Interior, Natl. Park Serv., Olympic Natl. Park, Port Angeles, Wash.

This report evaluates survival of native plant species 1 year after transplanting in an upper elevation conifer forest of Olympic National Park. Survival ranged from 0 to 80 percent, depending on species. Suggested means of increasing survival were: watering plants before transplanting, adding organic matter to the soil, and pruning foliage to reduce water loss. Such trailing plants and mat-forming plants as *Rubus lasiococcus, Luina hypoleuca, Phlox diffusa,* and *Luetkea pectinata* yielded the best results. Tree seedlings (*Abies lasiocarpa, A. amabilis,* and *Tsuga mertensiana*) over 12 in (30 cm) tall and under 2 in (5.1 cm) tall had very high mortality. Species with less than 40 percent survival included: *Pachistima myrsinites, Phyllodoce empetriformis, Xerophyllum tenax, Rhododendron albiflorum, Vaccinium membranaceum, Cassiope mertensiana,* and *Chamaecyparis nootkatensis.* Some of these species should be tried again under better conditions because the number of transplants was too small (usually one or two). Most of the area was covered with jute netting to hold soil in place and to denote restoration areas to visitors. A table of results and a list of suggested additional species are included.

265. Scott, R. L.

1977. Revegetation studies of a disturbed subalpine community in Olympic National Park, Washington. Unpubl. rep., 62 p. Seattle Pac. Univ., Seattle, Wash.

Treatments of topsoil from an adjacent area and fertilizer pellets (22-8-2) were used on transplants of *Abies amabilis* (Pacific silver fir), *Tsuga mertensiana* (mountain hemlock), *Xerophyllum tenax,* and *Phyllodoce empetriformis.* Transplanting was accomplished in September and all plots were covered with jute netting and watered immediately after planting and several times during the next growing season. No statistical tests were run on the data, but results were interesting: the greatest mortality occurred the winter after transplanting rather than the following summer; fertilizing had no apparent effect on rate of survival, which was 70 percent with fertilization and 72 percent without; south-facing plots exhibited greater mortality than north-facing plots; survival by species was 92 percent for *Phyllodoce,* 83 percent for *Tsuga,* 67 percent for *Abies,* and 4 percent and 69 percent on south- and north-facing slopes, respectively, for *Xerophyllum*; and topsoil had no effect on survival except for a possible increase in *Phyllodoce.* This is a good example of a relatively small-scale revegetation project that can be completed by one or two people in a backcountry area.

266. Scotter, G. W.

1976. Recovery of subalpine meadows under protection after damage by human activities, Yoho National Park. Unpubl. rep., 22 p. Can. Wildl. Serv., Edmonton, Alta.

Rates of recovery for seven untreated exclosures in a subalpine meadow near Lake O'Hara were studied by comparing chart quadrats made 3 years apart. Growth from existing shoot and rootstocks was most rapid although some seedlings became established. Species recovering from rootstocks included: *Antennaria alpina, Vaccinium scoparium, Sibbaldia procumbens, Carex nigricans, Fragaria virginiana,* and *Potentilla nivea.* Seedlings established were: *Arenaria obtusiloba, Sibbaldia procumbens, Epilobium alpinum, Draba crassifolia, Poa* sp., *Poa paucispicula, Agrostis humilis, Juncus drummondii, Ranunculus eschscholtzii,* and *Sagina saginoides.* Plants within exclosures exhibited increased vigor and inflorescence production after 3 years. Based on the reduction per year of bare ground, recovery was quite slow, although different for each type of site. Sites examined included a fire ring, a tent area, bare areas under *Abies lasiocarpa,* trails, and a mixed herbaceous community.

267. Scotter, G. W.

1978. Subalpine revegetation study, Mount Revelstoke National Park. Prog. Note 2. Unpubl. rep., 8 p. Can. Wildl. Serv., Edmonton, Alta.

Transplants of *Luetkea pectinata* and other species reported in Campbell and Scotter (1974, reference *201*) were reexamined 3 years after planting. Water, fertilizer, and topsoil enhanced the survival of *Luetkea,* but success was sometimes high when no treatment was applied. The larger plug size of 15 to 20 cm^2 resulted in the highest survival. It was suggested that the 7 to 10 cm^2 plug size was most economical, however. Of the other species transplanted, *Antennaria lanata, Castilleja rhexifolia, Carex spectabilis,* and *Luzula glabrata* were most successful. These species exhibited good vigor and were setting seed. Species with 25 to 100 percent survival, but only poor-to-fair condition were: *Juncus drummondii, Valeriana sitchensis, Anemone occidentalis,* and *Arnica mollis.* Additional transplants, planted in 1976 by a contract crew, were not surviving well due to frost heaving. The author stressed the importance of moving plants to and from areas with similar ecological conditions.

268. Smith, J. G.

1963. A subalpine grassland seeding trial. J. Range Manage. 16:208-210.

In a seeding trial at 5,700 ft (1 739 m) elevation in central Washington, 14 grasses and eight legumes were planted in June. Legume seed was inoculated with nitrogen-fixing bacteria

and legume plots received broadcast gypsum at 200 lb/acre (224 kg/ha). Half of each grass plot received 200 lb/acre (224 kg/ha) of ammonium sulfate fertilizer. Each species was sown in a monoculture. *Phleum pratense, Agropyron trachycaulum, Elymus glaucus, Poa ampla, Bromus erectus,* and *Agropyron trichophorum* were rated excellent after eight seasons. *Agropyron subsecundum* was the only grass to completely fail. *Astragalus cicer* and three varieties of *Medicago sativa* showed good establishment the first year, but declined rapidly and were present in sparse quantities after 3 years. This lack of success with legumes was also reported by Dyrness (1975, reference *213*). A favorable, but short-lived, response to nitrogen was noted in the grasses.

269. Steen, O., and W. A. Berg.

1975. Bibliography pertinent to disturbance and rehabilitation of alpine and subalpine lands in the southern Rocky Mountains. Environ. Resour. Cent. Inf. Ser. 14, 104 p. Colo. State Univ., Fort Collins.

This is an annotated bibliography with 455 references. Topics include: climate, geology, soils and substrates, native vegetation, disturbance, and rehabilitation. The work provides a good introduction to the literature on the disturbance and rehabilitation of alpine and subalpine ecosystems. Subject and author indexes are provided and material is cross referenced.

270. Stevens, D. R.

1979. Problems of revegetation of alpine tundra. *In* Proc. Conf. Sci. Res. in Natl. Parks. p. 241-245. R. M. Linn, ed. U.S. Dep. Interior, Natl. Park Serv., Trans. Proc. Ser. 5. Gov. Print. Off., Washington, D.C.

This paper provides a good review of what is known about revegetation and factors limiting plant establishment in Rocky Mountain National Park. Transplants established on roadcuts in 1933 have survived, but have not increased in size. The factors considered most important in limiting plant establishment were lack of moisture, high winds, and low nutrient status of soils. Some experiments were conducted on an old building site. Transplanting turf was more successful than adding topsoil, mulches, and snow fences to reduce windspeed. Availability of turf material for transplanting, however, limited the use of this technique. Seedlings of lower elevation introduced species (*Rumex* spp. and *Chenopodium* spp.) were found after the first year. These were probably transported to the site in topsoil. Using topsoil from other locations always involves the risk of bringing in unwanted species, and it may not be possible to eliminate introduced species brought in in this manner.

271. Sundahl, W. E.

1974. Fine cleaning of small seeds by static electricity. Tree Plant. Notes 25(2):2.

Small quantities of seed were cleaned in one plastic and one glass beaker. The plastic beaker was charged with static electricity from wiping with a dry nylon cloth. Chaff and empty seeds tended to cling to the side of the beaker so unwanted material could be wiped out and the process repeated until seed was sufficiently clean.

272. Thalheimer, J. F.

1967. A test of rotated use, watering and seeding for maintaining vegetation under simulated recreational use. M.S. thesis. Utah State Univ., Logan. 51 p.

Understory vegetation under lodgepole pine and aspen, in two campgrounds in northeast Utah, responded favorably to a combination of watering, fertilization, and seeding. Individually none of these treatments had a pronounced effect. Furthermore, herbage production was greatest on sample plots that were used every other week. Where use was continuous or more highly concentrated (all use confined to only 1 week of a 3-week period), production was lower. These results should be treated with caution due to problems with use simulation, the short study period, and questions about its applicability to other vegetation types. Some elements of this study were continued for a longer period of time and were reported in Beardsley and Wagar (1971, reference *195*).

273. Thorud, D. B., and S. S. Frissell.

1969. Soil rejuvenation following artificial compaction in a Minnesota oak stand. Minn. For. Res. Note 208, 4 p.

Sandy loam to loamy sand soils in an undisturbed oak forest in Minnesota were artifically compacted with a gas-powered tamper. Bulk density increased from an initial value of 1.14 g/cm^3 to 1.45 g/cm^3 immediately after compaction. During the 4.5-year study period this decreased to 1.24 g/cm^3. Linear projections suggested that complete recovery would take approximately 6 years. The authors suggest rest-rotation as a management technique for restoring compacted soil. Other investigators suggest, however, that the time required to compact soil from recreational use is much less than the subsequent recovery time (see Merriam and others [1973, reference *98*]).

274. Thorud, D. B., and S. S. Frissell.

1976. Time changes in soil density following compaction under an oak forest. Minn. For. Res. Note 257, 4 p.

Changes in soil density after artificial compaction were examined after 8¾ years. The bulk density of the 0 to 3 in (0 to 7.6 cm) layer had returned to precompaction levels, but the 6 to 9 in (15 to 23 cm) layer exhibited no recovery; bulk density remained at 1.55 g/cm^3 (1.43 for the control). There was no significant change in soil density on control sites during the study period. The results verify the prediction of Thorud and Frissell (1969, reference *273*) that approximately 6 years would be required for the surface soil layer to recover from compaction.

275. Tinus, R. W., and S. E. McDonald.

1979. How to grow tree seedlings in containers in greenhouses. USDA For. Serv. Gen. Tech. Rep. RM-60, 256 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

This is a comprehensive guide to the development and operation of a greenhouse for container-grown tree seedlings. Enough detail is included to help managers decide whether or not to build a greenhouse. Topics include growing media, container types, building design, pest management, tree physiology, growing schedules, hardware, and environmental control. Principles included here apply to greenhouses in general, but the scale of the operation is larger than would be needed for most backcountry rehabilitation projects.

276. Van Horn, J.

1977. Sunrise restoration report, 1977 season. Unpubl. rep., 26 p. U.S. Dep. Interior, Natl. Park Serv., Mount Rainier Natl. Park, Longmire, Wash.

This report summarizes rehabilitation work and observations on restoration projects for the east side of Mount Rainier National Park. Work included erosion control and transplanting of trails and setting up experiments to determine whether a cold

frame was necessary to propagate divisions and cuttings. The most pertinent observations were: visitor education is the best long-term solution to some problems; helicopters were cheaper than backpacking as a means of transporting large quantities of soil to backcountry sites; helicopters for transporting fill help reduce trampling from crews on site, but are noisy; jute netting has probably been used too often and needs to be securely anchored and perhaps buried to a 1-inch depth for best results; and trails can be narrowed through placement of rocks, logs, and transplants (diagrams are provided), but erosion must be controlled if treatments are to be effective. *Festuca rubra,* an introduced grass, was planted in earlier years to establish a quick ground cover on some backcountry sites and many roadcuts. It was thought at the time of seeding that native species would eventually out-compete the fescue and that no viable seed would be produced. Observations by the author indicate that native species have not replaced the fescue in approximately 8 years and that seed is being produced. Viability, however, was unknown at the time of the report. The importance of using native species to maintain the natural integrity of the vegetation is stressed.

277. Wagar, J. A.
1965. Cultural treatment of vegetation on recreation sites. Proc. Soc. Am. For. 61:37-39.

This is a general discussion of how fertilizer, water, mulches, and overstory thinning can be used to increase vegetation on developed campgrounds. Results of the studies mentioned here were only preliminary and are reviewed in detail elsewhere (see Beardsley and Wagar [1973, reference *195*]). Mulch was recommended as a treatment where vigorous tree and shrub growth was desired, but ground cover was not important. Overstory thinning was suggested as a means to increase light intensities, while still providing some shade to help plants recover from trampling damage.

278. Wagner, W. L., W. C. Martin, and E. F. Aldon.
1978. Natural succession on strip-mined lands in northwestern New Mexico. Reclam. Rev. 1:67-73.

Plant species composition and diversity were compared on mined and unmined lands at the McKinley Coal Mine in New Mexico. Mine spoils were between 1 and 13 years old. The vegetation of all mined areas was composed primarily of introduced annuals and a mixture of native and introduced perennials. There were fewer introduced annuals and perennials on unmined sites. After 13 years of recovery, all mined areas were considered to be in a similar phase of early primary succession, suggesting slow natural recovery. Species diversity on mined areas showed no significant relation to the age of the site, although a trend from annuals toward herbaceous perennials was discernible as the time since disturbance increased. It was suggested that native colonizers be seeded to enhance recovery. Recommended native species included: *Atriplex canescens, A. powellii, A. saccaria, A. rosea, Agropyron smithii, Sitanion hystrix, Chrysothamnus nauseosus,* and *C. greenei.*

279. Willard, B. E., and J. W. Marr.
1971. Recovery of alpine tundra under protection after damage by human activities in the Rocky Mountains of Colorado. Biol. Conserv. 3:181-190.

Exclosures were established to evaluate recovery of disturbed tundra sites. An area which had been trampled for only 1 year recovered its natural appearance in two seasons. The data presented show no significant increase in cover over the observation period, however. Following the same recovery period, an area which had been trampled for 26 years still showed visible evidence of impact despite increases in cover and species number. An exclosure that reduced, but did not eliminate use, had essentially no effect. Interesting observations included: a species' ability to survive trampling and its ability to recover under protection were not correlated; and seedling survival was greater on exposed B and C horizons than on exposed A horizons. The general conclusion was that almost complete recovery of sites used for only 1 year takes only two growing seasons, while recovery in areas used for longer periods of time may take from several hundred to a thousand years.

280. Young, J. A., R. A. Evans, B. L. Kay, and others.
1978. Collecting, processing, and germinating seeds of Western wildland plants. USDA Sci. and Educ. Admin., Agric. Rev. Man. ARM-W-3, 38 p. Berkeley, Calif.

This is an excellent guide for collecting, storing, and germinating seeds of noncommercial species.

281. Zuck, R. H., and L. F. Brown, eds.
1976. Proc., Revegetation of High-altitude Disturbed Lands Workshop, No. 2. Environ. Resour. Cent. Inf. Ser. 21, 128 p. Colo. State Univ., Fort Collins.

The second of three workshops on high altitude revegetation (see Berg and others [1974, reference *197*], and Kenny [1978, reference *236*]). The papers in this volume contain quite a few details on methods of revegetation that are applicable to backcountry areas. Some of these are: plant establishment, cleaning of seed, special problems with revegetation at higher elevations, seed collection, species suitability ratings, and several reports on specific revegetation projects. Most of the papers deal with high altitude revegetation in general rather than backcountry areas.

RELATED REFERENCES

282. Abbot, H. G., and S. D. Fitch.
1977. Forest nursery practices in the United States. J. For. 75:141-145.

This paper summarizes the general practices of and number of seedlings produced by 99 forest nurseries throughout the United States. The most useful information is a table of chemicals employed to control nursery pests and diseases.

283. Amen, R. D.
1965. Seed dormancy in the alpine rush, *Luzula spicata* L. Ecology 46: 361-364.

This study of *Luzula spicata* seeds from the alpine tundra of the Colorado Front Range revealed complete dormancy due to conditions of the seedcoat. The only effective treatment in breaking dormancy was scarification of the micropylar end of the seed. The duplication of this kind of mechanical action on the seedcoat under natural conditions was thought to be caused by abrasive action of soil particles. Seeds from different locations, collected in different years, did not vary in the extent or degree of dormancy exhibited, nor did they vary significantly in their response to scarification or other treatments. Maximum germination was 90 percent with scarification, and 0 for controls.

284. Amen, R. D.
1966. The extent and role of seed dormancy in alpine plants. Quar. Rev. Biol. 41:271-281.

The mechanisms of seed dormancy were found to be as diverse and frequent in alpine plants as in any other ecological group. Seed germination data from the 62 species suggested that seedcoat inhibition was the most common cause of alpine seed dormancy. Seedcoat inhibition can be alleviated by scarification and may be related to the frequency of abrasive action produced by soil disturbances and wind in the alpine zone. Experimental investigations showed that only a relatively small proportion of alpine species were actually dormant in the seed stage, and that few of these required a cold treatment (stratification) for effective germination. These results differ from those of Mirov (1936, reference *329*) which showed an increasing need for stratification with increasing elevation, although Mirov did not really differentiate alpine species from higher elevation species. Amen also reported that the same species collected at different locations sometimes exhibited different germination requirements.

285. Amen, R. D., and E. K. Bonde.

1964. Dormancy and germination in alpine *Carex* from the Colorado Front Range. Ecology 45:881-884.

The nature of achene dormancy was studied in *Carex albonigra* and *C. ebenea* from the Rollins Pass area of the Colorado Front Range. Germination was determined under treatments of stratification, scarification, leaching, extraction, exposure to light, and application of several plant growth regulators. In *C. albonigra,* only scarification at the basal end of the achenes resulted in germination, while only fluorescent or red light was effective in promoting germination of *C. ebenea.* This light effect was apparently cumulative, with a minimum of about 15 days of continuous light being required.

286. Babb, T. A., and L. C. Bliss.

1974. Effects of physical disturbance on arctic vegetation in the Queen Elizabeth Islands. J. Appl. Ecol. 11:549-562.

The most applicable part of this paper describes recovery of disturbed sites in arctic Canada. On entirely denuded areas, the most rapid reinvaders are the most efficient seed and bulbil producers and, in some places, mosses. Woody perennials and lichens recovered much more slowly. On less disturbed sites, mechanically protected and resistant species recovered most rapidly. In all cases, recovery was extremely slow. Manuring accelerated this recovery but often led to shifts in species composition. Although arctic and alpine vegetations have significant differences, some of these conclusions could also be applied to alpine disturbances.

287. Ballard, T. M.

1972. Subalpine soil temperature regimes in southwestern British Columbia. Arct. and Alp. Res. 4:139-146.

Temperature regimes for bare ground, evergreen shrub, herbaceous meadow, single tree, and tree clump sites are reported in this paper. Diurnal temperature amplitudes are presented for each situation as a percent of the bare ground values. Surface temperatures of 120° F (49° C) were potentially lethal for tree seedlings on the herbaceous meadow sites in early summer. This often-cited paper reveals the extreme temperatures that occur at the soil surface in the subalpine zone. Such extremes are especially probable in disturbed sites. Such sites require amelioration to enhance rehabilitation success with seeds and seedlings.

288. Barnes, K. K., W. M. Carleton, H. M. Taylor, and others, eds.

1971. Compaction of agricultural soils. Monogr., Am. Soc. Agric. Eng., St. Joseph, Mich. 471 p.

This book provides a detailed summary of current knowledge about soil compaction, written by various experts in the field. Some of the topics discussed are the soil compaction process, methods of measuring soil compaction, effects of soil compaction on other soil properties, effects of soil compaction on plant growth, and natural agents which alleviate compaction problems. Although the emphasis is on agricultural soils, some insights can be gained concerning compaction in areas of recreational use.

289. Barton, H., W. G. McCully, H. M. Taylor, and J. E. Box, Jr.

1966. Influence of soil compaction on emergence and first-year growth of seeded grasses. J. Range Manage. 19:118-121.

Grass seeds were sown in plots which received different levels of soil compaction. The number of seedlings which emerged was not affected by compaction. With increasing compaction, however, there were decreases in plant height, pounds of seed, and pounds of forage produced. Roots were unable to penetrate the sandy clay loam soil where bulk density exceeded 1.82 g/cm^3.

290. Bates, G. H.

1950. Track making by man and domestic animals. J. Anim. Ecol. 19:21-28.

This paper discusses differences in the physics of treading by humans and by domestic animals. It notes reasons for the development of permanent footpaths and deviations from this norm. It could be useful in designing paths and evaluating differential impact by humans and packstock.

291. Baver, L. D.

1933. Some soil factors affecting erosion. Agric. Eng. 14(2):51-52.

Early review of soil factors which affect the amount of runoff and the movement of soil by water. Runoff is affected most by the absorptive capacity and permeability of the soil; runoff and (usually) erosion are greater on finely textured soils which are low in organic matter. Ease of dispersion by water and (usually) erosion are also greater on finely textured soils which are low in organic matter. Complications and contradictions to these generalizations are common (for example, Farmer and Van Haveren [1971, reference *305*] and Wischmeier and Mannering [1969, reference *347*]).

292. Bliss, L. C.

1958. Seed germination in arctic and alpine species. Arctic 11:180-188.

This study examined the germination of arctic and alpine plant species under continuous 72° F (22° C) temperatures in petri dishes. One set of seeds for each species was kept in the dark and the other in light. Twenty-two of 36 (61 percent) of the arctic species germinated while 21 of 26 (80 percent) of the alpine species germinated. No great differences were found between the average germination percentages of the various species from the two tundras; 13 of 22 arctic species and 10 of 21 alpine species germinated at the 50 percent level or better. None of the arctic or alpine species germinated exclusively in the dark, but nine of the 43 did so only in the light. All the arctic species tested that were usually found growing on deeply

ıawed soil, with the exception of *Salix alaxensis* (fetleaf wil-w), germinated in both light and darkness. Of those arctic ıecies that most frequently occurred on the wet tundra soils at thawed shallowly, only 48 percent germinated under both ;ht and dark; some with very low percentages. The arctic ıecies are presented separately for the deeply thawed and ıallowly thawed soils. All species appear in the index.

)3. Blom, C. W. P. M.

1976-1977. Effects of trampling and soil compaction on the occurrence of some *Plantago* species in coastal sand dunes. I. Soil compaction, soil moisture and seedling emergence. Oecol. Plant. 11:225-241. II. Trampling and seedling establishment. Oecol. Plant. 12:363-381.

These experiments examined the emergence and seed-ıg establishment of several species of a noted trampling-ısistant genus (*Plantago*) in response to soil compaction and ampling. At optimal soil moisture levels, more emergence ccurs on loose soils. At low soil moisture, in the sand dune soils udied, more seedlings emerged on the compacted soils. This as apparently a response to the greater amount of capillary ater in the compacted soil, an advantage which over-hadowed the negative effect of the soil's greater mechanical ısistance. This suggests that compaction in soils with low ater-holding capacities is beneficial to some species. Re-ponses to trampling vary considerably among the *Plantago* pecies, with *P. major* being the most tolerant of trampling tress. A good study of the complex, interacting factors which ause the specific responses to trampling noted in more general tudies.

94. Bonde, E. K.

1965. Further studies on the germination of seeds of Colorado alpine plants. Univ. Colo. Stud., Ser. Biol. 18:1-30.

This paper presents the results of seed germination tudies on 59 alpine species from the Colorado Front Range. Seeds were stored at room temperature and germinated in the lark. The two tests used involved waiting 3 months and 9 nonths after collection before germination was attempted.

!95. Bonham, C. D.

1972. Vegetation analysis of grazed and ungrazed alpine hairgrass meadows. J. Range Manage. 25:276-279.

By comparing grazed and ungrazed *Deschampsia caes-pitosa* meadows in Colorado and Wyoming, the author identi-ies changes in species composition attributable to historic sheep grazing. Similar methods could be used if managers wanted to determine some of the effects of packstock grazing.

!96. Brink. V. C.

1964. Plant establishment in the high snowfall alpine and subalpine regions of British Columbia. Ecology 45:431-438.

Reasons for the lack of plant establishment on bare soil adjacent to well-developed vegetation were examined in this study. Lack of establishment was attributed to needle ice, snow slides, and interfacial frost. Soil texture-vegetation interrela-tionships are discussed with reference to the development of terraces, stone streams, and hummocks. The paper provides insight into factors that need to be controlled before revegeta-tion will be successful at high elevations. No ideas about how to control these processes are given.

297. Brink, V. C., J. Mackay, S. Freyman, and D. G. Pearce.

1967. Needle ice and seedling establishment in south-western British Columbia. Can. J. Plant Sci. 47:135-139.

In some years, needle ice may occur frequently enough in southwestern British Columbia to cause serious damage to late seedings of sports turf, lawns, and forage. When earlier seeding cannot be undertaken, increased seeding rates to secure dense stands may reduce damage done by needle ice. Needle ice was a factor of considerable potential in the erosion of lightly vege-tated or nonvegetated slopes. Damage from the ice occurs when crystals grow, lifting soil particles, seedlings, and duff several centimeters, and then melt. Damaged or dead seed-lings, a highly erodible surface, and the movement downslope of a substantial amount of material result. In compacted soils, damage is likely to be greater than in uncompacted soils. Nee-dle ice probably contributes importantly to mortality of plants in rehabilitation projects, even at lower elevations.

298. Chan, F. J., R. W. Harris, A. T. Leiser, and J. L. Paul.

1969. Factors influencing depth of seeding. Tree Plant. Notes 20(2):1-5.

Procedures for determining optimum seeding depth are described in this paper and results are given for the following species: *Prosopis tamarugo* (mesquite), *Eucalyptus vininalis* (eucalyptus), and *Pinus radiata* (Monterey pine). Seed size, soil temperature, and soil texture were shown to be important con-siderations. *Prosopis*, for example, had best emergence when sown at depths of 0.5 in (13 mm), 0.1 in (3 mm), and 0.4 in (11 mm) for clay, loam, and sand, respectively. A greater seeding depth was required for larger seeds or warmer temperatures. This kind of information can be useful for reseeding projects, but may not be worth obtaining unless extensive seeding is planned.

299. Colorado Mountain Trails Foundation.

[n.d.] Mountain trails: some guidelines on environmen-tal inventory and a selected bibliography. 25 p. Little-ton, Colo.

This paper provides 10 guidelines for environmental in-ventory work associated with trail planning and design. It also contains a very select bibliography (not annotated) on ecology, geology and soils, vegetation, water, wildlife, and recreation. A bibliography, developed by M. J. Liddle, on the ecological effects of recreation is also included.

300. Copes, D. L.

1977. Influence of rooting media on root structures and rooting percentage of Douglas-fir cuttings. Silvae Genet. 26:102-106.

Combinations of perlite, vermiculite, and sphagnum peat were used to determine the best mix for both rooting habit and survival of *Pseudotsuga menziesii* (Douglas-fir) cuttings. Cut-tings 2 to 3 in (5.0 to 7.5 cm) long were obtained from 2-to-4-year-old greenhouse seedlings in April and were treated with Captan, an insecticide-fungicide, but no root hormones. Great-er proportions of sphagnum peat gave more highly branched root systems while greater proportions of perlite gave relatively poor, short, thick root systems. Sand was associated with long, unbranched roots. Rooting percentages from 68 to 78 percent were obtained from the following, listed from highest to lowest: 1:1 perlite-sand, 1:2 vermiculite-sand, 2:1 vermiculite-perlite, 1:1 vermiculite-sand, 1:2 vermiculite-sphagnum peat. Mixtures with peat tended to become saturated easily, while perlite or

sand mixtures dried out quickly. An optimum mix was suggested as being a compromise between highest rooting percentage and best root structure. This would probably include vermiculite, sand or perlite, and sphagnum peat, perhaps 1:1:1. Miller and Miller (1976, reference *247*) have successfully used a mixture of 1:1:1 sand-peat-perlite.

301. Dahlgreen, A. K., R. A. Ryker, and D. L. Johnson.
1974. Snow cache seedling storage: successful systems. USDA For. Serv. Gen. Tech. Rep. INT-17, 12 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.

Storing seedlings on site or near the location where they are to be planted allows more freedom in choosing planting times and eliminates the need for expensive storage facilities. This paper describes two different storage systems in some detail, with guidelines for site selection. A cache that is properly constructed can safely provide storage for up to 3 months or more.

302. Donard, G. B., and C. W. Cook.
1970. Carbohydrate reserve content of mountain range plants following defoliation and regrowth. J. Range Manage. 23:15-19.

The carbohydrate reserves of six mountain range plants were measured when plants achieved 10 percent defoliation by clipping. Plants were clipped in early spring and late spring, the times of normal minimum and maximum carbohydrate reserve levels, respectively. *Agropyron inerme, Stipa lettermanii, Symphoricarpos vaccinioides,* and *Geranium fremontii* showed a depletion of total available carbohydrates after defoliation and regrowth. Grass and forb species were affected more by early-spring clipping than late-spring clipping, provided that sufficient regrowth occurred before the onset of fall dormancy. Shrub species seemed to be affected about the same by early- or late-spring clipping. This is one of the few papers that show possible physiological explanations of why plants are extra sensitive to disturbance (trampling) early in the growing season. Hartley (1976, reference *50*) shows that with repeated human trampling, carbohydrate reserves are reduced and plants then have fewer flowers and shorter stature.

303. Edmond, D. B.
1966. The influence of animal treading on pasture growth. Proc. Int. Grassl. Congr. 10:453-458.

This paper summarizes 10 years of work by the author on the effects of experimental sheep trampling in New Zealand. The often dramatic impact of treading (in addition to grazing) on yield and species composition is well illustrated. Impacts were greater on moist than on dry soils.

304. Emerson, W. W., R. D. Bond, and A. R. Dexter, eds.
1978. Modification of soil structure. John Wiley and Sons, New York. 438 p.

This is a compendium of papers dealing with the mechanics of soil structure, its modification by farming, and methods for improvement. The book is aimed at agricultural situations, but some information may prove useful for rehabilitation work since compaction causes a drastic change in soil structure.

305. Farmer, E. E., and B. P. Van Haveren.
1971. Soil erosion by overland flow and raindrop splash on three mountain soils. USDA For. Serv. Res. Pap. INT-100, 14 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.

The severity of erosional losses is a function of vegetation, soil, precipitation, and topography. A complete vegetation cover is of the utmost importance in minimizing erosion. Where vegetation cover is sparse, the effects of rainfall intensity and topography on amount of erosion are an order of magnitude more important than any soil variable. This suggests that in the area studied, Idaho and Utah, topographic factors are more important criteria in deciding where to locate facilities than soil factors.

306. Federer, C. A., G. H. Tenpas, D. R. Schmidt, and C. B. Tanner.
1961. Pasture soil compaction by animal traffic. Agron. J. 53:53-54.

Plant yield and soil aeration were reduced significantly on sites in Wisconsin grazed by dairy cattle. Penetration resistance and bulk density increased. These changes, attributable to treading, did not intensify after the first year of grazing. This is another example of initial impacts causing most of the observed change. The consequences of grazing by packstock should be generally similar.

307. Forristal, F. F., and S. P. Gessel.
1955. Soil properties related to forest cover type and productivity on the Lee Forest, Snohomish County, Washington. Soil Sci. Soc. Am. Proc. 19:384-389.

The most useful part of this paper provides observations on the maximum bulk density that roots of some tree species can penetrate. This could prove helpful in making species selections for transplanting into compacted soils. Maximum bulk densities (g/cm^3) for tree species were: *Thuja plicata* (western redcedar), 1.8; *Alnus rubra* (red alder), 1.5; *Pseudotsuga menziesii* (Douglas-fir) and *Tsuga heterophylla* (western hemlock), 1.25.

308. Frenkel, R. E.
1970. Ruderal vegetation along some California roadsides. Univ. Calif. Publ. Geogr. 20:1-163.

A thorough discussion of vegetation growing in humanly disturbed areas in California that is most valuable for its summary of information on plants which inhabit frequently trampled areas. The following are common characteristics of these plants: diminutiveness, spreading habit or rosette formation, small leaves, hemicryptophytic or therophytic life form, attenuated lifespan under unfavorable conditions, good nutrient uptake and regeneration, strong and thick cell walls, flexible vegetative parts, ability to spread and reproduce vegetatively, small hard seeds and seeds that germinate after scarification, small flowers, autogamous reproduction, short root to flower distance, short period for reaching seed maturity, large seed production per plant, and seed dispersal by external attachment to animals. Useful for predicting which species will survive trampling and which might be useful in a revegetation attempt.

309. Grime, J. P.
1973. Control of species density in herbaceous vegetation. J. Environ. Manage. 1:151-167.

The author advances the theory that maximum plant species richness (the number of species in a given unit area) occurs at intermediate levels of environmental stress. At these levels highly competitive species capable of excluding many less competitive species are not widespread, but stress is not so great that only a few species can survive. This suggests that maximum species richness could be expected in areas which receive low levels of trampling stress.

310. Harper, J. L., P. H. Lovell, and K. G. Moore.
1970. The shapes and sizes of seeds. Annu. Rev. Ecol. Syst. 1:327-356.

This is a first-rate review of the adaptive significance of

eed shape and size which is related to the successional role a articular species plays. The paper, while detailed, may provide ssistance to people working in revegetation especially where tle is known about the species involved; for example, colo-izing species often have small seeds and may be recognized y this characteristic. The authors also discuss different echanisms of seed dormancy. This information will be useful those attempting seed germination experiments.

11. Harper, J. L., J. T. Williams, and G. R. Sagar.
    1965. The behaviour of seeds in soil. I. The heterogeneity of soil surfaces and its role in determining the establishment of plants from seed. J. Ecol. 53:273-286.

Experiments on the effects of soil surface on seed gerination of selected species were conducted by compacting e soil or placing different objects, such as glass and small oxes, on the soil surface. The microtopography of the soil urface was also mapped using a 10-point frame. Species used ere *Plantago lanceolata, P. major, P. media, Bromus rigidus,* *. madritensis, Chenopodium album,* and *Brassica oleracea.* he details of the results are less important than the finding that pecies responded differently to the varied microenvironments t the soil surface. The authors argue that the availability of uitable microsites on a soil surface offered a means by which e number of plants establishing from seed is regulated and the bundance of some species is determined.

12. Hartmann, H. T., and D. E. Kester.
    1975. Plant propagation principles and practice. (3d ed.) Prentice Hall, Engelwood Cliffs, New Jersey. 662 p.

This is an excellent reference manual for anyone involved propagating plants, from seed or from cuttings.

13. Hatchell, G. E., and C. W. Ralston.
    1971. Natural recovery of surface soils disturbed in logging. Tree Plant. Notes 22(2):5-9.

Recovery of soil, that is, the soil's return to normal bulk ensity values, required about 18 years on the average. Lull 1957, reference *319*) maintains that compaction from tramling is often as severe as compaction from heavy logging quipment.

14. Heidmann, L. J., and D. B. Thorud.
    1975. Effect of bulk density on frost heaving of six soils in Arizona. USDA For. Serv. Res. Note RM-293, 4 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

Frost heaving increases in severity with increased soil ompaction. As frost heaving is a common cause of tree seeding mortality, this could be an important factor, along with rampling, in the absence of tree seedlings on compacted ampsites. It also underscores the need to break up compacted oil when attempting revegetation.

15. Hulme, J. K.
    [n.d.] Propagation of alpine plants. Alp. Gard. Soc., London. 30 p.

This is a good, easy-to-understand guide on propagation of alpine plants from seed or cuttings. It has plenty of details, but is essentially nontechnical. Examples are provided for species that are difficult to propagate; some of these are included in the index.

316. Johnson, W. M., J. O. Blankenship, and G. R. Brown.
    1965. Explorations in the germination of sedges. USDA For. Serv. Res. Note RM-51, 8 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

Nine treatments were applied to 27 subalpine and alpine species of *Carex* from Wyoming to determine the best method of achieving germination. The tests were conducted in petri dishes under greenhouse conditions. The following 12 species had germination of 10 percent or less under all tests (highest germination percent in parentheses): *Carex aquatilis* (0), *C. albonigra* (8), *C. athrostachya* (10), *C. kelloggii* (7), *C. lanuginosa* (0), *C. media* (5), *C. physocarpa* (1), *C. praegracilis* (0), *C. pseudoscirpoidea* (0), *C. raynoldsii* (3), *C. rostrata* (0), *C. scopulorum* (2). Species with greater than 65 percent germination and the best method of achieving germination were as follows: *C. ebenea* (tap water leaching); *C. egglestonii* (30-day cold); *C. illota* (control); *C. limnophila* (24-hour cold); *C. microptera* (soil leachate); *C. nelsonii* (soil leachate); and *C. phaeocephala* (24-hour cold). All others species fell between 10 and 65 percent germination; *C. atrata, C. chalciolepis, C. epapillosa, C. hoodii, C. nebraskensis, C. nova, C. petasata,* and *C. tomiei. Carex ebenea* germinated readily under several of the conditions applied in this study, but Amen and Bonde (1964, reference *285*) found the species responded only to red or fluorescent light. It may be that treatment effects in the study by Johnson and others (1965, reference *316*) have been obscured by placing seeds under bright light conditions. They did note that a dark treatment inhibited germination in all species. In most cases, seeds given a 90-day cold treatment germinated less than the controls and always less than seeds given shorter cold treatments.

317. Kozlowski, T. T., ed.
    1972. Seed biology. (3 vols.) Academic Press, New York.

This work contains most of the information one might want about seeds. The three volumes cover a range of topics including: metabolism, pathology, germination, longevity, storage, physiology, and collection. A fairly exhaustive list of species with known longevity of seeds is included.

318. Lowdermilk, W. C.
    1930. Influence of forest litter on runoff, percolation and erosion. J. For. 28:474-491.

Experiments comparing bare-soil and litter-covered surfaces in California showed dramatic increases in runoff and erosion on bare surfaces. Both of these increases were more pronounced on fine-textured soils. For example, runoff from a bare fine sandy loam was three times the runoff from a similar litter-covered soil, while runoff from a bare clay loam was 16.5 times the runoff from the litter-covered soil. Moreover, differences in amounts of material eroded from bare-soil and litter-covered surfaces were much greater than differences in runoff. This illustrates the importance of maintaining a litter-covered surface.

319. Lull, H. W.
    1959. Soil compaction on forest and range lands. USDA For. Serv. Misc. Publ. 768, 33 p. Washington, D.C.

This is a good review of knowledge (as of 1959) about soil compaction and its application to forest and range situations. The author discusses compaction resulting from logging, trampling, and raindrop impact. Other subjects include a discussion of the trampling process, the major independent variables which determine the amount of compaction that occurs, and the effects of soil compaction on soil-water relations and vegetation. Some points of interest were: compaction by raindrops is

significant and may be almost as great on bare ground under a tree canopy as on bare ground in the open; compaction by trampling may be as great as that caused by heavy logging equipment; the soils which have the greatest potential compactibility are medium-textured soils with a wide range in particle size; compaction is more severe when soils are moist and low in organic matter, and when they have low initial densities; compaction increases bulk density, reduces total pore space by the same proportion, reduces noncapillary pore space by a greater amount, and has its greatest effect on infiltration rates; and compaction levels reach a maximum relatively rapidly, beyond which only a great increase in applied force can cause further increases in compaction.

320. Lunt, H. A.

1937. The effects of forest litter removal upon the structure of the mineral soil. J. For. 35:33-36.

The soil properties of an untreated soil sample were compared with those of a soil sample which had its litter cover removed 2.5 years previously. In this short period, the aggregate content and reciprocal of volume weight (bulk density) in the upper inch of the bare soil was reduced to 60 to 65 percent and 81 percent, respectively, of the untreated soil. These changes could easily contribute to increased erosion, illustrating the significance of a litter cover.

321. McDonough, W. T.

1969. Effective treatments for the induction of germination in mountain rangeland species. Northwest Sci. 43:18-22.

Mountain rangeland species examined in this study fell into two groups with regard to seed germination: those that germinated readily with alternating temperatures, and those that required a low temperature treatment after the seeds had imbibed water (stratification). Species in both groups germinated the best when gibberellic acid (GA_3) was added. It was suggested that a cold treatment of seed in water or GA_3 for from 3 to 4 months would be successful for many species if other germination treatments such as scarification, leaching, and exposure to different photoperiods did not work. Species germinating without the cold treatment included: *Achillea millefolium, Agastache urticifolia, Aquilegia coerulea, Arabis glabra, Camelina microcarpa, Chrysothamnus viscidiflorus, Collomia linearis, Grindelia squarrosa, Hesperochloa kingii, Lupinus argenteus, Phleum alpinum, Pedicularis parryi, Penstemon rydbergii, Poa nevadensis, Poa foliosissimum, Potentilla glandulosa, P. gracilis, Rumex crispus, Taraxacum officinale, Thalictrum fendleri,* and *Tragopogon dubius.* Species aided by stratification were: *Actaea glabra, Agoseris glauca, Antennaria rosea, Berberis repens, Bromus polyanthus, Carex hoodii, Cirsium foliosum, Clematis hirsutissima, Descurainia pinnata, Elymus cinereus, E. glaucus, Frasera speciosa, Geranium viscosissimum, Heracleum lanatum, Ligusticum filicinum, L. porteri, Madia glomerata, Sambucus racemosa, Senecio integerrimus,* and *S. serra.* Seeds were collected from the Wasatch and Uinta Mountains of Utah and the Centennial Mountains of Montana.

322. McDonough, W. T.

1969. Seedling growth of ten species of subalpine rangeland in Utah as affected by controlled diurnal temperature alternations. Am. Midl. Nat. 82:276-279.

Seedlings of 10 subalpine rangeland species from Utah were grown in environmental chambers with day temperatures of 68° F (20° C) and night temperatures ranging from 36° to 68° F (2° to 20° C). Cooler night temperatures did not favor growth of these higher elevation species as hypothesized. Eight specie exhibited increased growth at higher night temperatures, but n particular night temperature was optimum. *Rumex crispus* an *Aquilegia coerulea* grew best with night temperatures of 59° I (15° C). Other species tested were: *Agastache urticifolia, Geur triflorum, Potentilla glandulosa, Rudbeckia occidentalis, Sibba dia procumbens, Thalictrum fendleri,* and *Tragopogon dubius* All species were stored at 36° F (2° C) and apparently germi nated successfully without stratification.

323. McDonough, W. T.

1974. Tetrazolium viability, germinability, and seedlin growth of old seeds of 36 mountain range plants USDA For. Serv. Res. Note INT-185, 6 p. Intermt. Fo and Range Exp. Stn., Ogden, Utah.

Seeds of 36 species of mountain range plants, 41 to 4 years old, were tested for viability and germinability. Twenty nine species gave negative reactions to the tetrazolium see viability test. Seven species, *Agastache urticifolia, Agoseri glauca, Melica bulbosa, Moldavica parviflora, Stipa co umbiana, S. lettermanii,* and *Polemonium foliosissimum,* ge minated with some success. The tetrazolium test described i this paper is useful because it allows for a check on viability

324. Meeuwig, R. O.

1970. Sheet erosion on Intermountain summer ranges USDA For. Serv. Res. Pap. INT-85, 25 p. Intermt. Fo and Range Exp. Stn., Ogden, Utah.

In a study utilizing simulated rainfall, plant, litter and, i some cases, stone cover explained most of the variance i amount of soil erosion. Other less significant independent vari ables were litter weight, slope gradient, and organic matter. Thi suggests the importance of maintaining a vegetation and litte cover on sites which are potentially erodible.

325. Meeuwig, R. O.

1971. Soil stability on high-elevation rangeland in th Intermountain area. USDA For. Serv. Res. Pap. INT 94, 10 p. Intermt. For. and Range Exp. Stn., Ogden Utah.

Soil characteristics which contribute to erodibility wer studied in western Idaho and eastern Utah. The most erodibl soils were high in clay and low in sand and organic matte Results are often directly contradictory to Wischmeier and Man nering (1969, reference *347*), illustrating the complex interac tions between factors which contribute to erodibility, and th difficulty of extrapolating findings from one area and soil type t another.

326. Megahan, W. F.

1977. Reducing erosional impacts of roads. *In* Guide lines for watershed management. p. 237-261. FA Conserv. Guide, Food Agric. Organ. U.N., Rome.

This is a summary of existing knowledge, some of whic could provide insights when attempting to reduce erosion alon trails. Major topics discussed include: erosional processes o roads, road location, road design, and revegetation.

327. Metheny, D., and L. I. Michaud.

1966. Cuttings through the year. (2d ed.) Arbor. Uni Counc. Governing Board, Seattle, Wash. 47 p.

This is a good guide for getting started with small-scal operations in cuttings. Procedures for taking cuttings are pre sented in a step-by-step outline and a table of the appropriat months for taking cuttings by genus is provided.

328. Minore, D., C. E. Smith, and R. F. Wollard.

1969. Effects of high soil density on seedling roo

growth of seven northwestern tree species. USDA For. Serv. Res. Note PNW-112, 6 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

This study showed that tree species have differential abilities to grow in compacted soils. The maximum soil bulk density that roots could penetrate was 1.32 g/cm^3 for western redcedar, Sitka spruce, and western hemlock, and 1.45 g/cm^3 for red alder, lodgepole pine, and Douglas-fir. (Compare with Forristall and Gessell [1955, reference *307*].)

329. Mirov, N. T.

1936. Germination behavior of some California plants. Ecology 17:667-672.

Germination behavior of 300 species of California seed plants was examined from an ecological perspective. Four main patterns of germination were observed: seeds that germinated without pretreatment; seeds that required some form of seedcoat rupture (scarification); seeds that needed after-ripening during a cold treatment (stratification); and seeds that required both after-ripening and rupture of the seedcoat. Conifer species germinated fairly well under ordinary greenhouse conditions, but stratification reduced the total germination time. Species in the families Compositae, Gramineae, Labiatae, and Scrophulariaceae germinated well without any pretreatment, while artificial rupture of the seedcoat was necessary for members of the Sterculiaceae, Anacardiaceae, and 16 of 39 species in the Leguminosae. Stratification was required by species in the family Ranunculaceae. A definite pattern between germination behavior and elevation was observed. A greater proportion of the higher elevations species than lower elevation species required stratification for successful germination.

330. Morby, F. E., and R. A. Ryker.

1975. Winter storage and packaging effects on Lucky Peak seedlings. USDA For. Serv. Res. Note INT-195, 10 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.

The effects of storing tree seedlings in crates or bags at temperatures of 28° F (−2° C) and 33° F (1° C) were examined for five tree species and one shrub species. There was no significant difference in survival or height growth between treatments for spring lifted stock, but the low temperature treatment reduced survival of stock lifted in the fall. The advantage to storing seedlings is that stock can be lifted at different times and held for later distribution. Some nurseries, for example, are unable to lift stock past a certain date because of frozen ground. In addition, lifting stock in the fall rather than spring frees growing space earlier in the year.

331. Nichols, G. E.

1934. The influence of exposure to winter temperatures upon seed germination in various native American plants. Ecology 15:364-373.

This is the only paper we have found that deals with germination of many plant species from the northeastern United States. The germination time and the number of seeds germinating are reported for 141 species collected in New England and Michigan. The author suggests that winter refrigeration of seeds is an important ecological factor in determining the northward distribution of plant species. Approximately 40 percent of the species examined showed increased germination after cold treatments. The period of germination observation was much greater than most studies (to 18 months). All species are included in the index.

332. Nikolaeva, M. G.

1967. Physiology of deep dormancy seeds. Israel Program Sci. Transl. Press, Jerusalem. 219 p. [Available from U.S. Dep. Commerce, Sci. Tech. Inf. Serv., Springfield, Va.]

An excellent detailed source of information on seed dormancy mechanisms and methods of breaking dormancy. It includes specific examples of how to break dormancy in difficult genera, such as *Acer, Sorbus, Crataegus, Fraxinus, Euonymus, Impatiens,* and *Ferula.* Several *Sorbus* species, for example, required from 1 to 4 months of cold stratification followed by up to 9 months of warm moist conditions to germinate successfully. The text is somewhat difficult to follow.

333. Orr, H. K.

1960. Soil porosity and bulk density on grazed and protected Kentucky bluegrass range in the Black Hills. J. Range Manage. 13:80-86.

The effects of grazing and trampling by range cattle were evaluated by examining exclosures which had been established 5 to 17 years previously. Significant decreases in bulk density and increases in macropore space were found in exclosures. Compaction effects were more pronounced and deeper on soils with large silt and clay fractions. Similar effects might be expected following grazing by packstock.

334. Owsten, P. W., and W. I. Stein.

1972. Coating materials protect Douglas-fir and noble fir seedlings against drying conditions. Tree Plant. Notes 23(3):21-23.

Clay slurry, *Xanthum* gum, and sodium alginate protected roots of freshly lifted *Pseudotsuga menziesii (Douglas-fir) and Abies procera* (noble fir) seedlings during 40 minutes of exposure to drying conditions. Control plants, dipped in distilled water, exhibited considerably greater moisture stress. Root coatings such as these should not be put on seedlings destined for storage, but can be useful for transplanting if plants are to be moved some distance. It is essential that roots be protected during transport.

335. Packer, P. E.

1953. Effects of trampling disturbance on watershed condition, runoff, and erosion. J. For. 51:28-31.

Studies of grasslands in Idaho subjected to experimental trampling by a steel "hoof" showed that the amount of trampling an area can receive, before unacceptable levels of erosion occur, is dependent upon the initial amount of cover. Heavy trampling may be tolerable if the ground cover is complete and bare soil openings are small. As total ground cover decreases, less trampling can be tolerated. Similar studies might be useful in setting some capacities on packstock use.

336. Pearcy, R. W., and R. T. Ward.

1972. Phenology and growth of Rocky Mountain populations of *Deschampsia caespitosa.* Ecology 53:1171-1178.

Plants of several populations of *Deschampsia caespitosa* collected in Colorado, northwestern Wyoming, and western Montana were studied for patterns of ecotypic differentiation. Seeds were planted in three essentially similar gardens at elevation of 5,180 ft (1 580 m), 8,984 ft (2 740 m), and 11,705 ft (3 570 m). In each of the gardens, plants from higher elevation sites developed first and had shorter growth periods and less height than plants collected at lower elevations. Survival of all

plants was good, although some mortality after transplanting occurred at the highest elevation garden. Mortality also occurred from a root rot pathogen (*Rhizoctonia* sp.) in the low-elevation garden, particularly with plants from high elevations. A fungicide was effective in eliminating mortality. At the highest elevation garden, only plants from high-elevation sites had mature seeds. This study clearly demonstrates the importance of selecting plants for rehabilitation from similar sites or provinces to ensure success of both transplanting and work with seeds. The difficulties with root rot are noteworthy to people involved with propagating plants in greenhouses.

337. Pelton, J.
1956. A study of seed dormancy in eighteen species of high altitude Colorado plants. Butler Univ. Bot. Stud. 13:74-84.

Seeds collected in the Front Range and Elk Mountains were subjected to a variety of treatments. *Antennaria parvifolia, A. rosea, Cirsium americanum* (partially dormant), *Polygonum viviparum, Senecio mutabilis, Taraxacum officinale,* and *Trisetum spicatum* germinated readily without treatments. Dormant species fell into three categories: those in which dormancy was broken by acid or mechanical scarification (*Androsace septentrionalis, Epilobium halleanum, Galium bifolium,* and *Thlaspi arvense*); those in which dormancy was broken by prolonged stratification under moist cold conditions (*Erythronium grandiflorum* and *Lomatium dissectum*); and those having seeds with complex dormancy mechanisms that could not be germinated (*Saxifraga rhomboidea, Hydrophyllum capitatum, H. fendleri, Mertensia fusiformis,* and *Sambucus microbotrys*). Tests on the latter species included higher germination temperatures, hot water, acid and mechanical scarification, cold stratification, light, and combinations of stratification and scarification.

338. Phipps, H. M.
1974. Growing media affect size of container-grown red pine. USDA For. Serv. Res. Note NC-165, 4 p. North Cent. For. Exp. Stn., St. Paul, Minn.

Pinus resinosa (red pine) seeds were grown in nine different soil media and two types of containers in a greenhouse. Growth differed significantly among the media after 16 weeks, with the largest seedlings produced in a 1:1 peat moss-vermiculite mix. Peat moss-vermiculite had the highest cation exchange capacity (143 meq/100 g) and lowest pH (5.0 to 5.6) of the media tested. The peat-vermiculite mix also retained moisture the longest and seedlings were removed with the least soil disturbance.

339. Sayers, R. L., and R. T. Ward.
1966. Germination responses in alpine species. Bot. Gaz. 127:11-16.

Germination studies were conducted on *Luzula spicata, Deschampsia caespitosa, Geum turbinatum, Pulsatilla ludoviciana, Sedum stenopetalum,* and *Trisetum spicatum. Luzula spicata* did not germinate, although successful germination is reported by Amen (1965, reference *283*). Germination values for most species were consistently high in the alternating temperature range of 50° to 68° F (10° to 20° C) for the low and 77° to 86° F (25° to 30° C) for the high. When the low temperature reached 32° F (0° C) germination was reduced. *Geum turbinatum, Deschampsia caespitosa,* and *Pulsatilla ludoviciana* showed a tendency to germinate better in light rather than dark. *Trisetum spicatum* germinated much better in the dark for the first 2 weeks, but after 4 weeks germination in the dark was less consistently superior. The relationship of plant densities in the field to germination tests is discussed.

340. Smart, A. W., and D. Minore.
1977. Germination of beargrass (*Xerophyllum tenax* (Pursch) Nutt.). Plant Propagator 23(3):13-15.

Xerophyllum tenax seeds collected near Mount Adams, Wash., were given several treatments to induce germination. Unstratified seeds failed to germinate, regardless of other treatments. Following a 24-hour presoak, seeds stratified in vermiculite at 37° F (3° C) for 16 weeks gave germination of 51 to 87 percent. The authors recommended germination temperatures of 64° F (18° C) and 55° F (13° C) for 12-hour days and 12-hour nights, respectively. *Xerophyllum* is an important native subalpine species in the Pacific Northwest. Greenhouse work with this species is now feasible and should aid revegetation work.

341. Steinbrenner, E. C.
1951. Effects of grazing on floristic composition and soil properties of farm woodlands in Southern Wisconsin. J. For. 49:906-910.

Grazed areas had a very different species composition than ungrazed areas. Grazed areas had more invader species, greatly reduced tree reproduction, and decreased organic matter content, air permeability, total pore space, macropore space, and water stable aggregate content. Other than a decrease in available potassium on grazed plots no differences in pH or nutrient content were found. Similar changes could be expected following packstock grazing.

342. Tanner, C. B., and C. P. Mamaril.
1959. Pasture soil compaction by animal traffic. Agron. J. 51:329-331.

Soils on grazed and ungrazed areas in Wisconsin were compared. Grazed areas had decreased air permeability and air capacity (porosity), and increased resistance to penetration and bulk density. Bulk density differences were much less pronounced than differences in the other characteristics. Only a coarse silt loam, with only 10 percent clay, did not change significantly in response to grazing. This has possible application to a better understanding of the impact of packstock on soil properties.

343. Thilenius, J. F.
1975. Alpine range management in the western United States — principles, practices, and problems: the status of our knowledge. USDA For. Serv. Res. Pap. RM-157, 32 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

A good review of alpine ecology, climate, and range management. Emphasis is on grazing, species utilization, range conditions and trends, and integrating grazing with concurrent use of land for watersheds, wildlife, recreation, and mining. Little attention is given to restoration, but the summary of alpine ecological processes is useful.

344. Tivy, J.
1973. The concept and determination of carrying capacity of recreational land in the U.S.A. Countryside Comm. Scotland Occas. Pap. 3, 58 p.

This is a review of the concept of carrying capacity written by a visiting geographer from Scotland. It contains definitions of various types of carrying capcity, a discussion of factors which affect carrying capacity, and some examples of how to determine carrying capacity. The second section is an annotated bibliography on carrying capacity and ecological impacts of recreation.

345. United States Department of Agriculture.
1974. Seeds of woody seed plants in the United States. U.S. Dep. Agric., Agric. Handb. 450, 883 p. Gov. Print. Off., Washington, D.C.

This book describes life histories, uses, and known germination requirements for many woody seed plants in the United States. This book should not be overlooked as a possible source of information on germinating seeds for revegetation work.

346. Veihmeyer, F. J., and A. H. Hendrickson.
1948. Soil density and root penetration. Soil Sci. 65:487-493.

For a given plant (in this case *Helianthus* sp.), the ability for roots to adequately penetrate compacted soil varied with the texture and moisture content of the soil. This qualifies the results of other researchers, such as Minore and others (1969, reference *328*) where maximum soil bulk densities that species can penetrate without regard to soil texture or moisture were reported.

347. Wischmeier, W. H., and J. V. Mannering.
1969. Relation of soil properties to its erodibility. Proc. Soil Sci. Soc. Am. 33:131-137.

Fifty-five soils from the Corn Belt were subjected to simulated rainfall and the resulting erosion was measured. A soil erodibility equation was developed, involving 22 parameters, which explained 95 percent of the variance. The most highly erodible soils were high in silt, low in clay, and low in organic matter. Particle-size distribution was the most important variable, with erodibility decreasing as silt decreased. Organic matter was also an important factor, tending to decrease the erodibility of most soils. Organic matter increased the erodibility of clay-rich soils, however. One should be cautious about applying these results to soils out of the textural range between silt and sandy loam and to soils which have been compacted at the surface.

348. Zak, B.
1975. Mycorrhizae and container seedlings. *In* Proc. 23d Annu. West. Int. For. Dis. Work Conf. p. 21-23.

The author points out that seedlings grown in containers may not survive, especially in sterile sites like mine spoils, if they have not been inoculated with mycorrhizae in the nursery. Difficulties with selecting the appropriate inoculations are discussed. The implication for rehabilitation work is that survival may be enhanced if plants can be properly inoculated.

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1979. Trampling and erosion in alpine country. J. Soil Conserv. Serv., N.S.W. 35(1):7-12.

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1967. A study of recreation and its impact on the environment in part of the New Forest, Hampshire. M.S. thesis. Univ. London.

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1979. Protecting the long trail resource: a problem analysis. *In* Long distance trails: the Appalachian Trail as a guide to future research and management needs. p. 84-103. W. R. Burch, Jr., ed. Sch. For. Environ. Stud., Yale Univ., New Haven, Conn.

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1977. Effects of visitor use on soil and vegetation of campground areas. M.S. thesis. Ohio State Univ., Columbus.

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1979. Impacts of off-road vehicles on infiltration and sediment production of two desert soils. J. Range Manage. 32:394-397.

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1976. Effect of snowmobile traffic on bluegrass (*Poa pratensis*). J. Environ. Qual. 5(2):129-131.

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Species Index for Rehabilitation Citations

The species index is arranged alphabetically by the scientific names used by the authors. Where nomenclature has changed, the currently accepted name is cross-referenced to the name used by the author. We have included an asterick (*) after species not native to the United States and upper-case letters to denote trees (T), shrubs (S), forbs (F), graminoids (G), cacti (C), and legumes (L). The numerals refer to the rehabilitation references that discuss the plant and are followed by lower-case letters in parentheses that indicate the kind of information included in the reference, where c = plant is a colonizing species; g = plant grown under greenhouse conditions; l = seeds given a laboratory germination test; p = number of pounds per acre is provided; r = recovery following human impact assessed; s = field seeding experiment; t = transplanting experiment; and u = utility for rehabilitation evaluated (usually for rangelands).

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Cole, David N., and Edward G. S. Schreiner, Compilers
1981. Impacts of backcountry recreation: site management and rehabilitation — an annotated bibliography. USDA For. Serv. Gen. Tech. Rep. INT-121, 58 p. Intermt. For. and Range Exp. Stn., Ogden, Utah 84401.

Over 300 references on recreational impacts, impact management, and rehabilitation of impacted sites are briefly reviewed. Their implications for backcountry management are assessed. References are indexed by location, subject, and plant species used for rehabilitation.

KEYWORDS: bibliography, backcountry management, recreational impact, site rehabilitation

The Intermountain Station, headquartered in Ogden, Utah, is one of eight regional experiment stations charged with providing scientific knowledge to help resource managers meet human needs and protect forest and range ecosystems.

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**Intermountain
Forest and Range
Experiment Station
Ogden, UT 84401**

General Technical
Report INT-122

April 1982

Aids to Determining Fuel Models For Estimating Fire Behavior

Hal E. Anderson

THE AUTHOR

HAL E. ANDERSON has been project leader of the Fuel Science Research Work Unit since 1966. He joined the staff of Intermountain Station's Northern Forest Fire Laboratory at Missoula, Mont., in 1961. He served as project leader of the fire physics project from 1962 to 1966. Prior to employment with the Forest Service, he was with the General Electric Co. and worked on thermal and nuclear instrumentation from 1952 to 1961. His B.S. degree in physics was obtained at Central Washington University in 1952.

RESEARCH SUMMARY

This report presents photographic examples, tabulations, and a similarity chart to assist fire behavior officers, fuel management specialists, and other field personnel in selecting a fuel model appropriate for a specific field situation. Proper selection of a fuel model is a critical step in the mathematical modeling of fire behavior and fire danger rating. This guide will facilitate the selection of the proper fire behavior fuel model and will allow comparison with fire danger rating fuel models.

The 13 fire behavior fuel models are presented in 4 fuel groups: grasslands, shrublands, timber, and slash. Each group comprises three or more fuel models; two or more photographs illustrate field situations relevant to each fuel model. The 13 fire behavior fuel models are cross-referenced to the 20 fuel models of the National Fire Danger Rating System by means of a similarity chart. Fire behavior fuel models and fire danger rating fuel models, along with the fire-carrying features of the model and its physical characteristics, are described in detail.

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INTRODUCTION

During the past two decades in the United States, the USDA Forest Service has progressed from a fire danger rating system comprising two fuel models (USDA 1964), to nine models in 1972 (Deeming and others 1972), and to 20 models in 1978 (Deeming and others 1977). During this time the prediction of fire behavior has become more valuable for controlling fire and for assessing potential fire damage to resources. A quantitative basis for rating fire danger and predicting fire behavior became possible with the development of mathematical fire behavior models (Rothermel 1972). The mathematical models require descriptions of fuel properties as inputs to calculations of fire danger indices or fire behavior potential. The collections of fuel properties have become known as fuel models and can be organized into four groups: grass, shrub, timber, and slash. Fuel models for fire danger rating have increased to 20 while fire behavior predictions and applications have utilized the 13 fuel models tabulated by Rothermel (1972) and Albini (1976). This report is intended to aid the user in selecting a fuel model for a specific area through the use of photographic illustrations. A similarity chart allows the user to relate the fire behavior fuel models to the fire danger rating system fuel models. The chart also provides a means to associate the fire danger rating system fuel models with a photographic representation of those fuel types.

HOW FUEL MODELS ARE DESCRIBED

Fuels have been classified into four groups—grasses, brush, timber, and slash. The differences in fire behavior among these groups are basically related to the fuel load and its distribution among the fuel particle size classes. This can be illustrated by the shift in size class containing the maximum fraction of load when considering the four fuel groups shown in figure 1. Notice that the fraction of the total load in the less than ¼-inch (0.6-cm) size class decreases as we go from grasses to slash. The reverse is true for the 1- to 3-inch (2.5- to 7.6-cm) material. In grasses, the entire fuel load may be herbaceous material less than one-fourth inch (0.6 cm), but grass may include up to 25 percent material between one-fourth and 1 inch (0.6 and 2.5 cm) and up to 10 percent material between 1 and 3 inches (2.5 cm and 7.6 cm). Each fuel group has a range of fuel loads for each size class, with maximum fuel load per size class approximately as shown in figure 1.

Fuel load and depth are significant fuel properties for predicting whether a fire will be ignited, its rate of spread, and its intensity. The relationship of fuel load and depth segregates the 13 fuel models into two distinctive orientations, with two fuel groups in each (fig. 2). Grasses and brush are vertically oriented fuel groups, which rapidly increase in depth with increasing load. Timber litter and slash are horizontally positioned and slowly increase in depth as the load is increased. Observations of the location and positioning of fuels in the field help one decide which fuel groups are represented. Selection of a fuel model can be simplified if one recognizes those features that distinguish one fuel group from another.

The 13 fuel models (table 1) under consideration are presented on page 92 of Albini's (1976) paper, "Estimating Wildfire Behavior and Effects." Each fuel model is described by the fuel load and the ratio of surface area to volume for each size class; the depth of the fuel bed involved in the fire front; and fuel moisture, including that at which fire will not spread, called the moisture of extinction. The descriptions of the fuel models include the total fuel load less than 3 inches (7.6 cm), dead fuel load less than one-fourth inch (0.6 cm), live fuel load of less than one-fourth inch (0.6 cm), and herbaceous material and fuel depth used to compute the fire behavior values given in the nomographs.

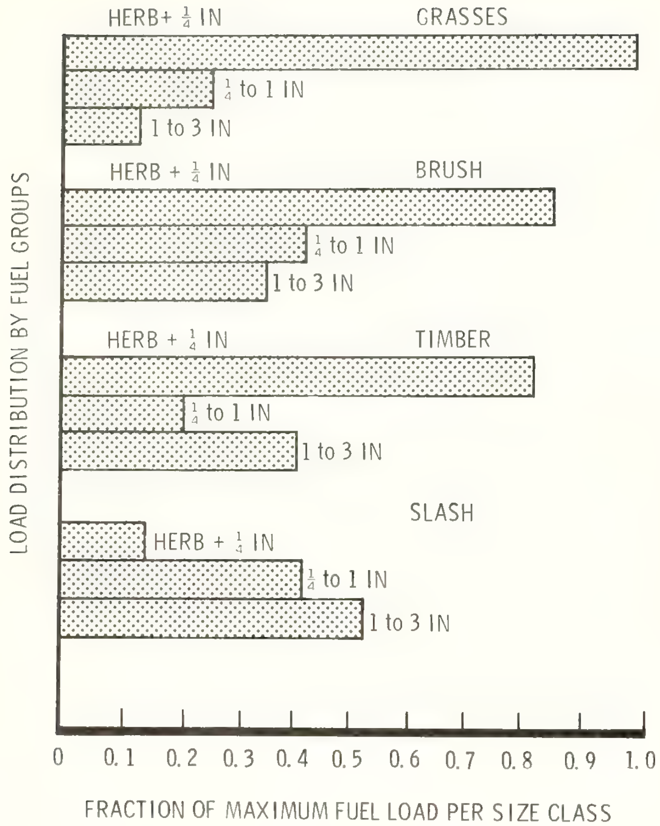

Figure 1.—Distribution of maximum fuel load by size class for each of the four general fuel groups. Note the shift in less than ¼-inch (0.6-cm) and 1- to 3-inch (2.5- to 7.6-cm) material

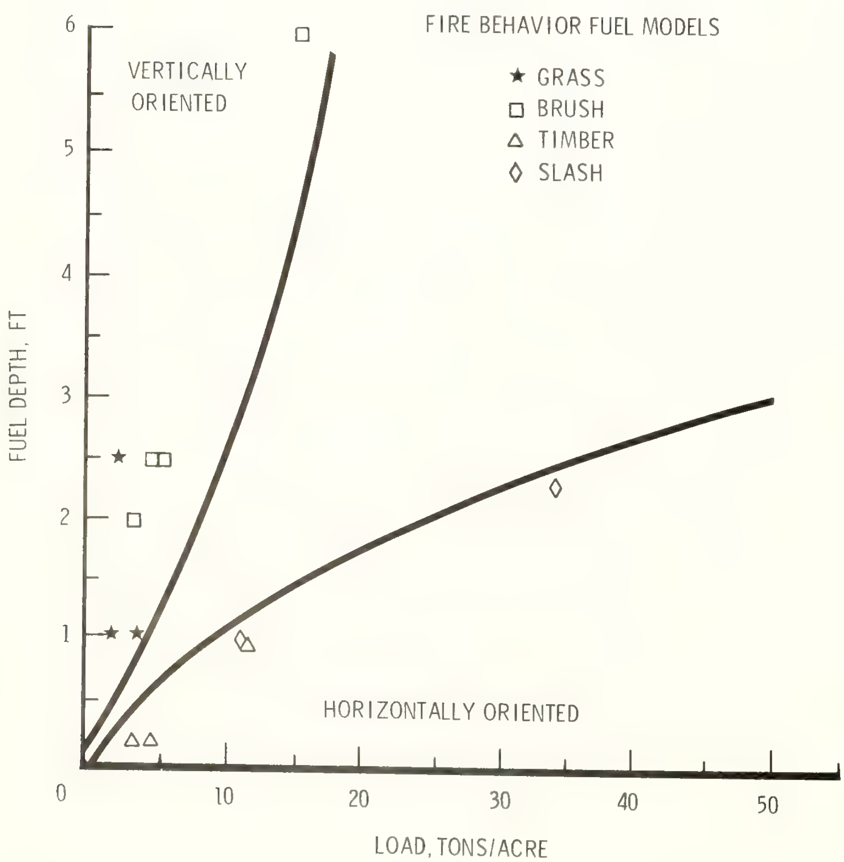

Figure 2.—The four general fuel groups are oriented in two basic directions: vertically, as in grasses and shrubs, and horizontally, as in timber, litter, and slash.

Table 1.— Description of fuel models used in fire behavior as documented by Albini (1976)

Fuel model	Typical fuel complex	Fuel loading				Fuel bed depth	Moisture of extinction dead fuels
		1 hour	10 hours	100 hours	Live		
		Tons/acre				*Feet*	*Percent*
	Grass and grass-dominated						
1	Short grass (1 foot)	0.74	0.00	0.00	0.00	1.0	12
2	Timber (grass and understory)	2.00	1.00	.50	.50	1.0	15
3	Tall grass (2.5 feet)	3.01	.00	.00	.00	2.5	25
	Chaparral and shrub fields						
4	Chaparral (6 feet)	5.01	4.01	2.00	5.01	6.0	20
5	Brush (2 feet)	1.00	.50	.00	2.00	2.0	20
6	Dormant brush, hardwood slash	1.50	2.50	2.00	.00	2.5	25
7	Southern rough	1.13	1.87	1.50	.37	2.5	40
	Timber litter						
8	Closed timber litter	1.50	1.00	2.50	0.00	0.2	30
9	Hardwood litter	2.92	.41	.15	.00	.2	25
10	Timber (litter and understory)	3.01	2.00	5.01	2.00	1.0	25
	Slash						
11	Light logging slash	1.50	4.51	5.51	0.00	1.0	15
12	Medium logging slash	4.01	14.03	16.53	.00	2.3	20
13	Heavy logging slash	7.01	23.04	28.05	.00	3.0	25

The criteria for choosing a fuel model includes the fact that the fire burns in the fuel stratum best conditioned to support the fire. This means situations will occur where one fuel model represents rate of spread most accurately and another best depicts fire intensity. In other situations, two fuel conditions may exist, so the spread of fire across the area must be weighted by the fraction of the area occupied by each fuel. Fuel models are simply tools to help the user realistically estimate fire behavior. The user must maintain a flexible frame of mind and an adaptive method of operating to totally utilize these aids. For this reason, the fuel models are described in terms of both expected fire behavior and vegetation.

The National Fire Danger Rating System (NFDRS) depends upon an ordered set of weather records to establish conditions of the day. These weather conditions along with the 1978 NFDRS fuel models are used to represent the day-to-day and seasonal trends in fire danger. Modifications to the fuel models are possible by changes in live/dead ratios, moisture content, fuel loads, and drought influences by the large fuel effect on fire danger. The 13 fuel models for fire behavior estimation are for the severe period of the fire season when wildfires pose greater control problems and impact on land resources. Fire behavior predictions must utilize on-site observations and short-term data extrapolated from remote measurement stations. The field use situation generally is one of stress and urgency. Therefore, the selection options and modifications for fuel models are limited to maintain a reasonably simple procedure to use with fire behavior nomographs, moisture content adjustment charts, and wind reduction procedures. The NFDRS fuel models are part of a computer data processing system that presently is not suited to real-time, in-the-field prediction of fire behavior.

FUEL MODEL DESCRIPTIONS
Grass Group

Fire Behavior Fuel Model 1

Fire spread is governed by the fine, very porous, and continuous herbaceous fuels that have cured or are nearly cured. Fires are surface fires that move rapidly through the cured grass and associated material. Very little shrub or timber is present, generally less than one-third of the area.

Grasslands and savanna are represented along with stubble, grass-tundra, and grass-shrub combinations that met the above area constraint. Annual and perennial grasses are included in this fuel model. Refer to photographs 1, 2, and 3 for illustrations.

This fuel model correlates to 1978 NFDRS fuel models A, L, and S.

Fuel model values for estimating fire behavior

Total fuel load, < 3-inch dead and live, tons/acre	0.74
Dead fuel load, ¼-inch, tons/acre	.74
Live fuel load, foliage, tons/acre	0
Fuel bed depth, feet	1.0

Photo 1. *Western annual grasses such as cheatgrass, medusahead ryegrass, and fescues.*

Photo 2. *Live oak savanna of the Southwest on the Coronado National Forest.*

Photo 3: *Open pine—grasslands on the Lewis and Clark National Forest*

Fire Behavior Fuel Model 2

Fire spread is primarily through the fine herbaceous fuels, either curing or dead. These are surface fires where the herbaceous material, in addition to litter and dead-down stemwood from the open shrub or timber overstory, contribute to the fire intensity. Open shrub lands and pine stands or scrub oak stands that cover one-third to two-thirds of the area may generally fit this model; such stands may include clumps of fuels that generate higher intensities and that may produce firebrands. Some pinyon-juniper may be in this model. Photographs 4 and 5 illustrate possible field situations.

This fuel model correlates to 1978 NFDRS fuel models C and T.

Fuel model values for estimating fire behavior

Total fuel load, < 3-inch dead and live, tons/acre	4.0
Dead fuel load, ¼ inch, tons/acre	2.0
Live fuel load, foliage, tons/acre	0.5
Fuel bed depth, feet	1.0

Photo 4. Open ponderosa pine stand with annual grass understory.

Photo 5: Scattered sage within grasslands on the Payette National Forest.

Fire Behavior Fuel Model 3

Fires in this fuel are the most intense of the grass group and display high rates of spread under the influence of wind. Wind may drive fire into the upper heights of the grass and across standing water. Stands are tall, averaging about 3 feet (1 m), but considerable variation may occur. Approximately one-third or more of the stand is considered dead or cured and maintains the fire. Wild or cultivated grains that have not been harvested can be considered similar to tall prairie and marshland grasses. Refer to photographs 6, 7, and 8 for examples of fuels fitting this model.

This fuel correlates to 1978 NFDRS fuel model N.

Fuel model values for estimating fire behavior

Total fuel load, < 3-inch dead and live, tons/acre	3.0
Dead fuel load, ¼-inch, tons/acre	3.0
Live fuel load, foliage tons/acre	0
Fuel bed depth, feet	2.5

Fires in the grass group fuel models exhibit some of the faster rates of spread under similar weather conditions. With a windspeed of 5 mi/h (8 km/h) and a moisture content of 8 percent, representative rates of spread (ROS) are as follows:

Model	**Rate of spread** *Chains/hour*	**Flame length** *Feet*
1	78	4
2	35	6
3	104	12

As windspeed increases, model 1 will develop faster rates of spread than model 3 due to fineness of the fuels, fuel load, and depth relations.

Photo 6. Fountaingrass in Hawaii; note the dead component.

Photo 7. Meadow foxtail in Oregon prairie and meadowland.

Photo 8: Sawgrass "prairie" and "strands" in the Everglades National Park, Fla.

Shrub Group

Fire Behavior Fuel Model 4

Fire intensity and fast-spreading fires involve the foliage and live and dead fine woody material in the crowns of a nearly continuous secondary overstory. Stands of mature shrubs, 6 or more feet tall, such as California mixed chaparral, the high pocosin along the east coast, the pinebarrens of New Jersey, or the closed jack pine stands of the north-central States are typical candidates. Besides flammable foliage, dead woody material in the stands significantly contributes to the fire intensity. Height of stands qualifying for this model depends on local conditions. A deep litter layer may also hamper suppression efforts. Photographs 9, 10, 11, and 12 depict examples fitting this fuel model.

This fuel model represents 1978 NFDRS fuel models B and O; fire behavior estimates are more severe than obtained by models B or O.

Photo 9. Mixed chaparral of southern California; note dead fuel component in branchwood.

Fuel model values for estimating fire behavior

Total fuel load, < 3-inch dead and live, tons/acre	13.0
Dead fuel load, ¼-inch, tons/acre	5.0
Live fuel load, foliage, tons/acre	5.0
Fuel bed depth, feet	6.0

Photo 10. Chaparral composed of manzanita and chamise near the Inaja Fire Memorial, Calif.

Photo 11. Pocosin shrub field composed of species like fetterbush, gallberry, and the bays.

Photo 12. High shrub southern rough with quantity of dead limbwood.

Fire Behavior Fuel Model 5

Fire is generally carried in the surface fuels that are made up of litter cast by the shrubs and the grasses or forbs in the understory. The fires are generally not very intense because surface fuel loads are light, the shrubs are young with little dead material, and the foliage contains little volatile material. Usually shrubs are short and almost totally cover the area. Young, green stands with no dead wood would qualify: laurel, vine maple, alder, or even chaparral, manzanita, or chamise.

No 1978 NFDRS fuel model is represented, but model 5 can be considered as a second choice for NFDRS model D or as a third choice for NFDRS model T. Photographs 13 and 14 show field examples of this type. Young green stands may be up to 6 feet (2 m) high but have poor burning properties because of live vegetation.

Fuel model values for estimating fire behavior

Total fuel load, < 3-inch dead and live, tons/acre	3.5
Dead fuel load, ¼-inch, tons/acre	1.0
Live fuel load, foliage, tons/acre	2.0
Fuel bed depth, feet	2.0

Photo 13. Green, low shrub fields within timber stands or without overstory are typical. Example is Douglas-fir–snowberry habitat type.

Photo 14. Regeneration shrublands after fire or other disturbances have a large green fuel component, Sundance Fire, Pack River Area, Idaho.

Fire Behavior Fuel Model 6

Fires carry through the shrub layer where the foliage is more flammable than fuel model 5, but this requires moderate winds, greater than 8 mi/h (13 km/h) at midflame height. Fire will drop to the ground at low wind speeds or at openings in the stand. The shrubs are older, but not as tall as shrub types of model 4, nor do they contain as much fuel as model 4. A broad range of shrub conditions is covered by this model. Fuel situations to be considered include intermediate stands of chamise, chaparral, oak brush, low pocosin, Alaskan spruce taiga, and shrub tundra. Even hardwood slash that has cured can be considered. Pinyon-juniper shrublands may be represented but may overpredict rate of spread except at high winds, like 20 mi/h (32 km/h) at the 20-foot level.

The 1978 NFDRS fuel models F and Q are represented by this fuel model. It can be considered a second choice for models T and D and a third choice for model S. Photographs 15, 16, 17, and 18 show situations encompassed by this fuel model.

Fuel model values for estimating fire behavior

Total fuel load, < 3-inch dead and live, tons/acre	6.0
Dead fuel load, ¼-inch, tons/acre	1.5
Live fuel load, foliage, tons/acre	0
Fuel bed depth, feet	2.5

Photo 15. Pinyon-juniper with sagebrush near Ely, Nev.; understory mainly sage with some grass intermixed.

Photo 16. Southern hardwood shrub with pine slash residues.

Photo 17. Low pocosin shrub field in the south.

Photo 18. Frost-killed Gambel Oak foliage, less than 4 feet in height, in Colorado.

Fire Behavior Fuel Model 7

Fires burn through the surface and shrub strata with equal ease and can occur at higher dead fuel moisture contents because of the flammability of live foliage and other live material. Stands of shrubs are generally between 2 and 6 feet (0.6 and 1.8 m) high. Palmetto-gallberry understory-pine overstory sites are typical and low pocosins may be represented. Black spruce-shrub combinations in Alaska may also be represented.

This fuel model correlates with 1978 NFDRS model D and can be a second choice for model Q. Photographs 19, 20, and 21 depict field situations for this model.

Fuel model values for estimating fire behavior

Total fuel load, < 3-inch dead and live, tons/acre	4.9
Dead fuel load, ¼-inch, tons/acre	1.1
Live fuel load, foliage, tons/acre	0.4
Fuel bed depth, feet	2.5

The shrub group of fuel models has a wide range of fire intensities and rates of spread. With winds of 5 mi/h (8 km/h), fuel moisture content of 8 percent, and a live fuel moisture content of 100 percent, the models have the values:

Model	Rate of spread *Chains/hour*	Flame length *Feet*
4	75	19
5	18	4
6	32	6
7	20	5

Photo 19. Southern rough with light to moderate palmetto understory.

Photo 20. Southern rough with moderate to heavy palmetto-gallberry and other species.

Photo 21. Slash pine with gallberry, bay, and other species of understory rough.

Timber Group

Fire Behavior Fuel Model 8

Slow-burning ground fires with low flame lengths are generally the case, although the fire may encounter an occasional "jackpot" or heavy fuel concentration that can flare up. Only under severe weather conditions involving high temperatures, low humidities, and high winds do the fuels pose fire hazards. Closed canopy stands of short-needle conifers or hardwoods that have leafed out support fire in the compact litter layer. This layer is mainly needles, leaves, and occasionally twigs because little undergrowth is present in the stand. Representative conifer types are white pine, and lodgepole pine, spruce, fir, and larch.

This model can be used for 1978 NFDRS fuel models H and R. Photographs 22, 23, and 24 illustrate the situations representative of this fuel.

Fuel model values for estimating fire behavior

Total fuel load, < 3-inch, dead and live, tons/acre	5.0
Dead fuel load, ¼-inch, tons/acre	1.5
Live fuel load, foliage, tons/acre	0
Fuel bed depth, feet	0.2

Photo 22. Surface litter fuels in western hemlock stands of Oregon and Washington.

Photo 23. Understory of inland Douglas-fir has little fuel here to add to dead-down litter load.

Photo 24. Closed stand of birch-aspen with leaf litter compacted.

Fire Behavior Fuel Model 9

Fires run through the surface litter faster than model 8 and have longer flame height. Both long-needle conifer stands and hardwood stands, especially the oak-hickory types, are typical. Fall fires in hardwoods are predictable, but high winds will actually cause higher rates of spread than predicted because of spotting caused by rolling and blowing leaves. Closed stands of long-needled pine like ponderosa, Jeffrey, and red pines, or southern pine plantations are grouped in this model. Concentrations of dead-down woody material will contribute to possible torching out of trees, spotting, and crowning.

NFDRS fuel models E, P, and U are represented by this model. It is also a second choice for models C and S. Some of the possible field situations fitting this model are shown in photographs 25, 26, and 27.

Fuel model values for estimating fire behavior

Total fuel load, < 3-inch dead and live, tons/acre	3.5
Dead fuel load, ¼-inch, tons/acre	2.9
Live fuel load, foliage, tons/acre	0
Fuel bed depth, feet	0.2

Photo 25. Western Oregon white oak fall litter; wind tumbled leaves may cause short-range spotting that may increase ROS above the predicted value.

Photo 26. Loose hardwood litter under stands of oak, hickory, maple and other hardwood species of the East.

Photo 27. Long-needle forest floor litter in ponderosa pine stand near Alberton, Mont.

Fire Behavior Fuel Model 10

The fires burn in the surface and ground fuels with greater fire intensity than the other timber litter models. Dead-down fuels include greater quantities of 3-inch (7.6-cm) or larger limbwood resulting from overmaturity or natural events that create a large load of dead material on the forest floor. Crowning out, spotting, and torching of individual trees are more frequent in this fuel situation, leading to potential fire control difficulties. Any forest type may be considered if heavy down material is present; examples are insect- or disease-ridden stands, windthrown stands, overmature situations with deadfall, and aged light thinning or partial-cut slash.

The 1978 NFDRS fuel model G is represented and is depicted in photographs 28, 29, and 30.

Fuel model values for estimating fire behavior

Total fuel load, < 3-inch dead and live, tons/acre	12.0
Dead fuel load, ¼-inch, tons/acre	3.0
Live fuel load, foliage, tons/acre	2.0
Fuel bed depth, feet	1.0

The fire intensities and spread rates of these timber litter fuel models are indicated by the following values when the dead fuel moisture content is 8 percent, live fuel moisture is 100 percent, and the effective windspeed at midflame height is 5 mi/h (8 km/h):

Model	Rate of spread *Chains/hour*	Flame length *Feet*
8	1.6	1.0
9	7.5	2.6
10	7.9	4.8

Fires such as above in model 10 are at the upper limit of control by direct attack. More wind or drier conditions could lead to an escaped fire.

Photo 28. Old-growth Douglas-fir with heavy ground fuels.

Photo 29. Mixed conifer stand with dead-down woody fuels.

Photo 30. Spruce habitat type where succession or natural disturbance can produce a heavy downed fuel load.

Logging Slash Group

Fire Behavior Fuel Model 11

Fires are fairly active in the slash and herbaceous material intermixed with the slash. The spacing of the rather light fuel load, shading from overstory, or the aging of the fine fuels can contribute to limiting the fire potential. Light partial cuts or thinning operations in mixed conifer stands, hardwood stands, and southern pine harvests are considered. Clearcut operations generally produce more slash than represented here. The less-than-3-inch (7.6-cm) material load is less than 12 tons per acre (5.4 t/ha). The greater-than-3-inch (7.6-cm) is represented by not more than 10 pieces, 4 inches (10.2 cm) in diameter, along a 50-foot (15-m) transect.

The 1978 NFDRS fuel model K is represented by this model and field examples are shown in photographs 31, 32, and 33.

Fuel model values for estimating fire behavior

Total fuel load, < 3-inch dead and live, tons/acre	11.5
Dead fuel load, ¼-inch, tons/acre	1.5
Live fuel load, foliage, tons/acre	0
Fuel bed depth, feet	1.0

Photo 31. *Slash residues left after skyline logging in western Montana.*

Photo 32. *Mixed conifer partial cut slash residues may be similar to closed timber with down woody fuels.*

Photo 33. *Light logging residues with patchy distribution seldom can develop high intensities.*

Fire Behavior Fuel Model 12

Rapidly spreading fires with high intensities capable of generating firebrands can occur. When fire starts, it is generally sustained until a fuel break or change in fuels is encountered. The visual impression is dominated by slash and much of it is less than 3 inches (7.6 cm) in diameter. The fuels total less than 35 tons per acre (15.6 t/ha) and seem well distributed. Heavily thinned conifer stands, clearcuts, and medium or heavy partial cuts are represented. The material larger than 3 inches (7.6 cm) is represented by encountering 11 pieces, 6 inches (15.2 cm) in diameter, along a 50-foot (15-m) transect.

This model depicts 1978 NFDRS model J and may overrate slash areas when the needles have dropped and the limbwood has settled. However, in areas where limbwood breakup and general weathering have started, the fire potential can increase. Field situations are presented in photographs 34, 35, and 36.

Fuel model values for estimating fire behavior

Total fuel load, < 3-inch dead and live, tons/acre	34.6
Dead fuel load, ¼-inch, tons/acre	4.0
Live fuel load, foliage, tons/acre	0
Fuel bed depth, feet	2.3

Photo 34. Ponderosa pine clearcut east of Cascade mountain range in Oregon and Washington.

Photo 35. Cedar-hemlock partial cut in northern Idaho, Region 1, USFS.

Photo 36. Lodgepole pine thinning slash on Lewis and Clark National Forest. Red slash condition increases classification from light to medium.

Fire Behavior Fuel Model 13

Fire is generally carried across the area by a continuous layer of slash. Large quantities of material larger than 3 inches (7.6 cm) are present. Fires spread quickly through the fine fuels and intensity builds up more slowly as the large fuels start burning. Active flaming is sustained for long periods and a wide variety of firebrands can be generated. These contribute to spotting problems as the weather conditions become more severe. Clearcuts and heavy partial-cuts in mature and overmature stands are depicted where the slash load is dominated by the greater-than-3-inch (7.6-cm) diameter material. The total load may exceed 200 tons per acre (89.2 t/ha) but fuel less than 3 inches (7.6 cm) is generally only 10 percent of the total load. Situations where the slash still has "red" needles attached but the total load is lighter, more like model 12, can be represented because of the earlier high intensity and quicker area involvement.

The 1978 NFDRS fuel model I is represented and is illustrated in photographs 37 and 38. Areas most commonly fitting this model are old-growth stands west of the Cascade and Sierra Nevada Mountains. More efficient utilization standards are decreasing the amount of large material left in the field.

Fuel model values for estimating fire behavior

Total fuel load, < 3-inch dead and live, tons/acre	58.1
Dead fuel load, ¼-inch, tons/acre	7.0
Live fuel load, foliage, tons/acre	0
Fuel bed depth, feet	3.0

For other slash situations:

Hardwood slash. . . . . Model
Heavy "red" slash. . . . . Model
Overgrown slash. . . . . Model
Southern pine clearcut slash. . . . . Model

The comparative rates of spread and flame lengths for the slash models at 8 percent dead fuel moisture conten and a 5 mi/h (8 km/h) midflame wind are:

Model	Rate of spread Chains/hour	Flame length Feet
11	6.0	3.5
12	13.0	8.0
13	13.5	10.5

Photo 37. West coast Douglas-fir clearcut, quantity of cull high.

Photo 38. High productivity of cedar-fir stand can result in large quantities of slash with high fire potential.

CORRELATION OF FIRE BEHAVIOR FUEL MODELS AND NFDRS FUEL MODELS

The following section, which correlates fuel models used for fire behavior with those used for fire danger rating, should help fire behavior officers (FBO's), researchers, or other concerned personnel understand the relationship of the two sets of fuel models. For initial fire behavior estimates, the fuel model used for fire danger rating can be cross referenced to a fire behavior fuel model suitable for the general area of interest. It also provides useful background about the character of each fuel model so specific selections can be made where vegetation varies considerably. Combining this information with the photographic representations of each of the 13 fuel models presents the concept that a single fuel model may represent several vegetative groups. **It is important that one maintain an open, flexible impression of fuel models so as to recognize those vegetative groups with common fire-carrying characteristics.**

The correlation with the 1978 NFDRS fuel models allows conversion from fire danger trend measurements to field-oriented prediction of fire behavior. The great variety of fuel, weather, and site conditions that exist in the field means the user of fuel models and fire behavior interpretation methods must make observations and adjust his predictions accordingly. Calibration of the fire behavior outputs for the selected fuel model can allow more precise estimation of actual conditions. This has been practiced in the field by instructors and trainees of the Fire Behavior Officer's (FBO) School, S-590, and has provided a greater degree of flexibility in application.

The fuel models shown in figure 3 were alined according to the fuel layer controlling the rate of fire spread. Some second and third choices are indicated for situations where fire spread may be governed by two or more fuel layers, depending on distribution and moisture content. From the four climates used in the 1978 NFDRS, climate 3 was used, with the live herbaceous fuels 99.7 percent cured and a wind of 20 mi/h (32 km/h) at the 20-foot (6.1-m) level. These conditions could be expected in a number of FBO situations. Combined with the fuel moistures for the less-than-3-inch (7.6-cm) material, these conditions make it possible to relate the dynamic fuel models within the 1978 NFDRS to the fuel models associated with the fire behavior nomographs. Although the output values differ slightly, the rankings of the fuel models by rate of spread and fire intensity allowed correlation of the two sets of models. Note in figure 3 that both sets of fuel models are separated into the four general fuel groups. Some exceptions are noted where more than one fuel model should be considered because the plant communities involved contain fuel in more than one stratum. Most fuel types support surface or ground fires, but some grass or shrub situations will support crown fires. Such situations usually occur in fuels extending to the ground and do not extend to the crown fire that may occur in pole, sawtimber, or mature forests. Regeneration where the crown still is within 4 to 6 feet (1.22 to 1.83 m) of the ground may experience crowning under severe weather conditions.

For a greater appreciation of fuel models and their function in fire danger rating and fire behavior prediction, the reader should refer to the following publications:

- Rothermel, Richard C. 1972. "A mathematical model for predicting fire spread in wildland fuels."
- Deeming, John E., and others. 1977. "The National Fire-Danger Rating System."
- Deeming, John E., and James K. Brown. 1975. "Fuel models in the National Fire-Danger Rating System."
- Albini, Frank A. 1976. "Estimating wildfire behavior and effects."

In addition the approach to time since disturbance is presented in works such as Kessell and Cattelino (1978) and suggests advances that can be made with more data and sophistication.

PHYSICAL DESCRIPTION SIMILARITY CHART OF NFDRS AND FBO FUEL MODELS

NFDRS MODELS REALINED TO FUELS CONTROLLING SPREAD UNDER SEVERE BURNING CONDITIONS

NFDRS FUEL MODELS	FIRE BEHAVIOR FUEL MODELS													
	1	2	3	4	5	6	7	8	9	10	11	12	13	
A W. ANNUALS	X													GRASS
L W. PERENNIAL	X													GRASS
S TUNDRA	X					3rd			2nd					GRASS
C OPEN PINE W/GRASS		X							2nd					GRASS
T SAGEBRUSH W/GRASS		X			3rd	2nd								GRASS
N SAWGRASS			X											GRASS
B MATURE BRUSH (6FT)				X										SHRUB
O HIGH POCOSIN				X										SHRUB
F INTER. BRUSH					2nd	X								SHRUB
Q ALASKA BLACK SPRUCE						X	2nd							SHRUB
D SOUTHERN ROUGH						2nd	X							SHRUB
H SRT-NDL CLSD. NORMAL DEAD								X						TIMBER
R HRWD. LITTER (SUMMER)								X						TIMBER
U W. LONG-NDL PINE									X					TIMBER
P SOUTH, LONG-NDL PINE									X					TIMBER
E HRWD. LITTER (FALL)									X					TIMBER
G SRT-NDL CLSD. HEAVY DEAD										X				TIMBER
K LIGHT SLASH											X			SLASH
J MED. SLASH												X		SLASH
I HEAVY SLASH													X	SLASH
	GRASS			SHRUB				TIMBER			SLASH			

Figure 3.—Similarity chart to aline physical descriptions of fire danger rating fuel models with fire behavior fuel models.

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APPENDIX: EVOLUTION OF FUEL MODELS

Introduction

More than 64 years ago, foresters in the United States were concerned about fire danger and were attempting to develop methods to assess the hazard (Dubois 1914). The "inflammability" of a situation depended on four elements: (1) amount of ground fuels; (2) ease of ignition; (3) dryness of the cover; and (4) slope. Three fuel types were considered: grass, brush, and timber. In 1978, we are still concerned about fire danger and fire behavior. Through the use of mathematical fire behavior models (Rothermel 1972) and fire danger ratings (Deeming and others 1977), we can evaluate how fire danger changes with weather, fuels, and slope. In addition, the fire behavior officer on a fire can estimate the fire behavior for the next burning period if he can define the fuels (Albini 1976). Dubois grouped fuels as grass, brush, and timber, and these general groupings are still used with the addition of slash. Several fuel types or fuel models are recognized within each group. For fire danger rating, we have gone from two fuel models (USDA Forest Service 1964) to nine in 1972 (Deeming and others 1972) and 20 in 1978 (Deeming and others 1977). Research efforts to assist the fire behavior officer have utilized the 13 fuel models tabulated by Rothermel (1972) and Albini (1976).

Fuels Defined

Fuels are made up of the various components of vegetation, live and dead, that occur on a site. The type and quantity will depend upon the soil, climate, geographic features, and the fire history of the site. To a large extent, potential evapotranspiration and annual precipitation combinations with altitude and latitude changes can describe the expected vegetation and have been used for vegetation maps (Küchler 1967). An adequate description of the fuels on a site requires identifying the fuel components that may exist. These components include the litter and duff layers, the dead-down woody material, grasses and forbs, shrubs, regeneration and timber. Various combinations of these components define the major fuel groups of grass, shrub, timber and slash. Certain features of each fuel component or the lack of it contributes to the description of the fuels in terms suitable to define a fuel model. For each fuel component certain characteristics must be quantified and evaluated to select a fuel model for estimating fire behavior. The most important characteristics for each component are:

1. Fuel loading by size classes
2. Mean size and shape of each size class
3. Compactness or bulk density
4. Horizontal continuity
5. Vertical arrangement
6. Moisture content
7. Chemical content, ash, and volatiles.

Each of the above characteristics contributes to one or more fire behavior properties. Fuel loading, size class distribution of the load, and its arrangement (compactness or bulk density) govern whether an ignition will result in a sustaining fire. Horizontal continuity influences whether a fire will spread or not and how steady rate of spread will be. Loading and its vertical arrangement will influence flame size and the ability of a fire to "torch out" the overstory. With the proper horizontal continuity in the overstory, the fire may develop into a crown fire. Low fuel moisture content has a significant impact upon fire behavior affecting ignition, spread, and intensity; with high winds it can lead to extreme fire behavior. Certain elements of the fuel's chemical content, such as volatile oils and waxes, aid fire spread, even when moisture contents are high. Others, like mineral content, may reduce intensity when moisture contents are low. High fuel loads in the fine fuel size classes with low fuel moisture contents and high volatile oil contents will contribute to rapid rates of spread and high fire line intensities, making initial attack and suppression difficult.

How Fuels Have Been Described

In the expression of fire danger presented by Dubois (1914), the fuel types of grass, brush, and timber were defined, utilizing three causes—amount of fuel on the ground, lack of moisture in the cover, and slope—and two effects—ease of ignition and rate of fire growth or spread. As Dubois pointed out, however, not enough study had been made of rate of spread to effectively describe differences among the fuel types. Sparhawk (1925) conducted an extensive study of fire size as a function of elapsed time from discovery to initial attack by broad forest cover types. Twenty-one fire regions for the western United States and the Lake States were defined and up to seven forest types selected for each region. These forest types basically were grass, brush, timber, and slash descriptions. The ranking of area growth rates by type showed the highest growth rates occurred in grasses and brush types, followed by slash and open timber situations and concluding with low growth rates in closed timber types. Sparhawk made the following comment regarding his data:

> Rating obtained, therefore, will represent averages of fairly broad application, but may now show what can be expected on individual units. These factors can be allowed for only when the fire records and the inventory of our forest resources include information concerning them.

Show and Kotok (1929) reported on a preliminary study of forest cover as related to fire control. Study of the nine major cover types in northern California showed definite differences between them regarding fire danger, ignition risk, rate of spread, and type of fire and several other fire control subjects. They did not attempt to complete analysis proposed by Sparhawk because the variability of individual fires was so great and the classification of type and hazard classes was so incomplete. However, their nine cover types fit a broader classification of:

1. Woodlands and grasslands
2. Chaparral and brush fields
3. Timber cover types:
   a. western yellow pine and mixed conifer
   b. Douglas-fir
   c. sugar pine-fir and fir.

These cover types and their classification express the broad groupings of grass-dominated, brush-dominated, and timber-residue-dominated fuel groups. Timber residues can be either naturally occurring dead woody or activity-caused slash. In terms of fire behavior, these cover types could be characterized as follows:

Crown fires (occur in secondary or primary overstory)—chaparral and brush types.

Surface fires (occurs in surface litter, dead-down woody, and herbaceous material)—woodlands and grasslands; western yellow pine and mixed conifer; Douglas-fir.

Ground fires (occur in litter, duff, and subsurface organic material)—sugar pine-fir; fir type.

This work showed the complexity of establishing hour control needs and contributes to continued efforts to describe types in terms of fire growth and control difficulty.

Hornby (1935) developed a fuel classification system that formalized the description of rate of spread and resistance to control into classes of low, medium, high, and extreme. For the Northern Rocky Mountains, the standard timber types relative ranking was similar to that of Show and Kotok as well as work in Colorado by Bates (1923) and described by Hornby (1935):

1. Brush—grass
2. Ponderosa pine
3. Larch—fir
4. Douglas-fir and lodgepole pine
5. White pine and lodgepole pine
6. Subalpine fir
7. White fir and spruce.

Classification of these fuels was accomplished by utilizing 90 men experienced in fire hazard. A total of 42 ratings were assigned to typical fuels in Region 1. Hornby noted that a weakness of the system was the use of estimates rather than extensive accurate measurements, but until enough years of data had been collected on contributing influences, some procedures for rating fuels were needed. Adaptations of Hornby's approach have been utilized in the eastern United States (Jemison and Keetch 1942) and modified later in the West (Barrows 1951). Most Forest Service regions utilized some version of the Hornby rating method but generally assigned rate of spread values unique to their area, thereby reducing comparability. This is illustrated by a sampling of the number of ratings used by various regions and some of the variation that existed for rate of spread (ROS) classes.

Region	Year	No. of ratings	ROS (chains/hour)
Region 1	1969	234	High (51)
Region 1	1974	4	High (25)
Region 2	1972	59	High (25)
Region 3	1970	11	
Region 4	1972	48	High (30)
Eastern	1966	15	
Region 5	1973	17	
Region 6	1972	16 examples	High (25)
Region 8	1975		High (>10)
Region 9	1970	10	

The variation of ROS rating is due not so much to fuels alone as to the combination of fuels, climate, season, and local weather. These additional factors influence the quantity of live fuel and the moisture content of the dead fuels. Other agencies such as the BLM have utilized the approach for each management area and have a set of ratings for six areas.

Fuels became a consideration in fire danger ratings in the 1950's; in 1958 an effort was made to unify the eight fire danger rating systems into one national system (Deeming and others 1972). Two fuel conditions were considered—fuels sheltered under a timber cover and fuels in an open, exposed site. A relative spread index was developed and brought into general use by 1965. Review of the approach and the expressed need for the ignition, risk, and energy indexes resulted in a research effort that yielded the 1972 National Fire Danger Rating System (NFDRS). Fuels could be considered in greater detail because a mathematical fire spread model had been developed by Rothermel (1972). Nine specific descriptions of fuel properties, called fuel models, were developed for the NFDRS (Deeming and Brown 1975). Fahnestock (1970), in his guide "Two keys for appraising forest fire fuels," was among the first to use the Rothermel fire spread model. The keys provide tools for recognizing the differences in fuel types and identifying the relative fire hazard potential in terms of rate of spread or crowning. To use the keys, one must describe physical fuel properties in Fahnestock's terms: fine, small, medium for size classes and sparse, open, dense, fluffy, or thatched for compactness or combination of loading and depth. By keying on the fuel properties of the site, one of the 36 rate-of-spread ratings or one of the 24 crowning-potential ratings can be selected.

Fahnestock interpreted the size class descriptions for each fuel stratum according to the physical dimensions and timelags associated with the 1964 NFDRS. Timelag is the time necessary for a fuel size class to change 63 percent of the total expected change. These same descriptions were used when fuel models were developed to represent broad vegetative types of grasslands, brushfields, timbered land, and slash. Within each fuel model, the load was distributed by size or timelag classes, correlated with groupings of foliage and twigs, branchwood, and tree or shrub material as follows:

Size, diameter *Inch*	Timelag *Hours*
< 1/4	1
1/4 to 1	10
1 to 3	100
> 3	1,000[1]

[1]Large fuels or layers slow to respond are recognized in the fuel models available in the 1978 NFDRS.

The initial fuel models were documented by Rothermel (1972) and these 13 models were reduced to 9 models for the 1972 NFDRS (Deeming and others 1972). The original 9 fuel models, except for one, have been retained in the 1978 NFDRS and supplemented by 11 others to accom-

modate differences across the country. For fire behavior officer training, the 13 fuel models initially presented by Rothermel (1972) and Albini (1976) are currently being used. The 13 models encompass those of the 1972 NFDRS and can be correlated to the 1978 NFDRS models. At the present time, the fuel models have the broadest application, while other research is providing fuel models for specific applications (Kessell 1976, 1977; Bevins 1976; Kessell, Cattelino, and Potter 1977; Philpot 1977; Hough and Albini 1978; Rothermel and Philpot 1973).

Anderson, Hal E.

1982. Aids to determining fuel models for estimating fire behavior. USDA For. Serv. Gen. Tech. Rep. INT-122, 22p. Intermt. For. and Range Exp. Stn., Ogden, Utah 84401.

Presents photographs of wildland vegetation appropriate for the 13 fuel models used in mathematical models of fire behavior. Fuel model descriptions include fire behavior associated with each fuel and its physical characteristics. A similarity chart cross-references the 13 fire behavior fuel models to the 20 fuel models used in the National Fire Danger Rating System.

KEYWORDS: forest fuels, modeling, fire behavior

The Intermountain Station, headquartered in Ogden, Utah, is one of eight regional experiment stations charged with providing scientific knowledge to help resource managers meet human needs and protect forest and range ecosystems.

The Intermountain Station includes the States of Montana, Idaho, Utah, Nevada, and western Wyoming. About 273 million acres, or 85 percent, of the land area in the Station territory are classified as forest and rangeland. These lands include grasslands, deserts, shrublands, alpine areas, and well-stocked forests. They supply fiber for forest industries; minerals for energy and industrial development; and water for domestic and industrial consumption. They also provide recreation opportunities for millions of visitors each year.

Field programs and research work units of the Station are maintained in:

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Bozeman, Montana (in cooperation with Montana State University)

Logan, Utah (in cooperation with Utah State University)

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Forest Service

Intermountain Forest and Range Experiment Station Ogden, UT 84401

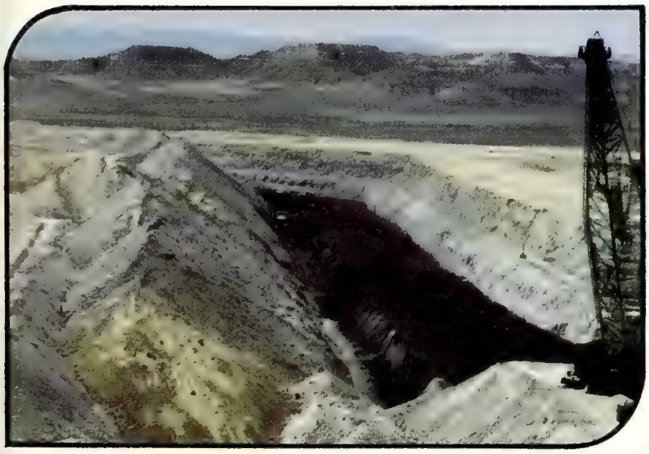
General Technical Report INT-123

August 1982

Models to Estimate Revegetation Potentials of Land Surface Mined for Coal in the West

Paul E. Packer, Chester E. Jensen, Edward L. Noble, and John A. Marshall

MINING



REVEGETATION

Kind of vegetation

$$\widehat{\text{Production}} = 0.0061896 \cdot \text{YPPR} \cdot \text{YPGS} \cdot (\text{PR})^{1.6} \cdot \begin{matrix} 1.04368 \text{ (native)} \\ 1.17448 \text{ (introduced)} \end{matrix}$$

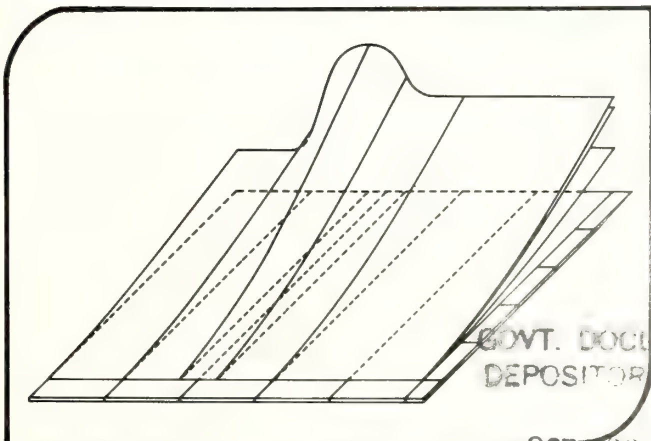
$$\text{YPPR} = e^{-\left|\frac{\frac{\text{AGE}}{7} - 1}{0.9}\right|^{4.8}}$$

If GS $\leq$ 85

$$\text{YPGS} = 940 + 2510 \cdot e^{-\left|\frac{\frac{\text{GS}}{85} - 1}{0.16}\right|^{4}}$$

If GS > 85

$$\text{YPGS} = 2250 + 1200 \cdot e^{-\left|\frac{\frac{\text{GS}}{85} - 1}{0.12}\right|^{4}}$$



RESEARCH DATA ANALYSIS

THE AUTHORS

PAUL E. PACKER, retired, served as Project Leader of the Intermountain Forest and Range Experiment Station's mine spoil reclamation research work unit. His experience as a research forester working on forest, range, and watershed rehabilitation problems in the Intermountain and Northern Rocky Mountain regions spans more than 40 years.

CHESTER E. JENSEN, retired, served as Principal Statistician for the Intermountain Forest and Range Experiment Station from 1967-80. He held the same position at the Northeastern and Central States Forest Experiment Stations prior to coming to the Intermountain Station.

EDWARD L. NOBLE, is a watershed and range management consultant. At the time of his retirement from the Forest Service in 1975, he was Branch Chief of Watershed Management for Region 4 (Intermountain Region).

JOHN A. MARSHALL, formerly systems analyst with the Intermountain Forest and Range Experiment Station, is now a computer specialist with National Forest Administration, Ketchikan, Alaska.

CONTENTS

RESEARCH SUMMARY

The primary objectives of this research were to develop capabilities for estimating the degree of revegetation success to be expected under a wide variety of climatic conditions, soil and spoil properties, and revegetation treatments utilizing site-specific revegetation data and information from most of the coal surface mines in the interior West. The more important study developments are these: A strong conceptual framework for evaluating the success of proposed vegetative rehabilitation efforts on areas to be surface mined. Site-specific maps to provide precipitation, growing season length, soil, and vegetation type information, critical to the evaluation system. Results of most existing surface-mine rehabilitation efforts in the interior West through 1976 were surveyed as a basis for evaluating revegetation success. Interim predictors (models) were developed, based on these survey data, for forage production and cover density potentials on undisturbed sites adjacent to the study mines and mined areas with various combinations of planting and postplanting methods and treatments designed to enhance the total rehabilitation effort for native species and introduced species.

This research shows that practical criteria for measuring revegetation success, namely, the amount of forage produced and the density of plant cover developed, are affected significantly by at least two major climatic factors (precipitation and growing season) that are not readily susceptible to alteration; by three properties of spoil materials (potassium, sodium, and pH) that are subject to limited modification through management. Revegetation success is also influenced by seven revegetation treatments, each of which provides at least two management alternatives, and by the age of the vegetation. These characteristics account for about one-half to three-fourths of the total variance in forage production and plant cover density in the prediction models.

Cover:

Mining: Spoils left in the wake of surface mining for coal in Montana.
Revegetation: A successful revegetation effort on spoils in Montana.
Research Data Analysis: *(left)* Equation for the interactive portion of one prediction model to estimate vegetative production on a mined, revegetated area. *(right)* Graphed equation for the interactive portion of one prediction model.

United States
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Forest Service

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Paul E. Packer, Chester E. Jensen, Edward L. Noble, and John A. Marshall

INTRODUCTION

An emerging problem in the interior West is the adverse effect on environmental quality of spoils left in the wake of surface mining for coal (cover photo, "Mining"). Needed are criteria and guides for predicting revegetation potentials on various kinds of surface-mined land. Equally important is the need to define and prescribe revegetation treatments, as well as posttreatment management measures, for such land.

Passage and implementation of the Surface Mining Control and Reclamation Act (Public Law 95-87) and attendant regulations have placed a new emphasis on revegetation of spoil materials from coal surface mines in North Dakota, Montana, Wyoming, Colorado, Utah, New Mexico, and Arizona. Although most coal companies in the interior West are applying revegetation practices to surface mines, requirements of the new Federal Reclamation Act, in many cases, will require a reassessment and evaluation of techniques and methodologies employed in present revegetation activities. Currently, many research activities are underway to determine the best "mix" of cultural practices and plant species needed to satisfactorily revegetate disturbed land (cover photo,"Revegetation"). In the interior West not enough time has elapsed, however, since surface mine revegetation activities began to give assurance that any particular combination of revegetation methods will be successful in the long run. Consequently, mining applicants, as well as administrators granting approval to mine, can only guess on the basis of limited experience whether the required reclamation standards can be met or not.

In view of this uncertainty regarding the probability for successfully revegetating western surface coal mines, an investigation, financed jointly by the Forest Service's Surface Environment and Mining (SEAM) project, the Environmental Protection Agency, and the Fish and Wildlife Service, was begun in 1976 to identify criteria for measuring the success of revegetation, to evaluate past and ongoing revegetation efforts at most of the major surface coal mines in the interior West, and to develop a capability for predicting the probable degree of revegetation success expected on coal lands that are surface mined in the future. That investigation and its results are the subject of this paper.

INVESTIGATIVE METHODS

Criteria as set forth by the Surface Mining Control and Reclamation Act (P.L. 95-87, Section 515 (6)(19)) require coal mine operators to "establish . . . a diverse, effective, and permanent vegetative cover of the same seasonal variety native to the area of land to be affected and capable of self-regeneration and plant succession at least equal in extent of cover to the native vegetation of the area; except that introduced species may be used in the revegetation process where desirable and necessary to achieve the approved post-mining land use plan."

Accordingly, investigative methods were based on the assumption that, unless some other revegetation objective is defined, the primary goal of revegetation on surface-mined coal areas in the interior West is to establish a productive and protective cover of durable plants, consisting primarily of species adapted to and characteristic of similar, but unmined areas. It was further assumed that differences in the degree of revegetation success to date on surface-mined coal lands in the West should be related to variations in natural climatic components, changes in site-specific physical and biological characteristics, and differences in the revegetation methods used.

The degree to which plant cover is established, either in natural or revegetated stands, can be measured and evaluated in a number of ways. One of the most important measures of success in plant cover establishment is the capability of the vegetation to produce aboveground biomass for forage or some other useful purpose. Another important measure of success is the capability of the vegetation to produce ground cover for protection of the soil against the erosive forces of raindrops and surface runoff. Accordingly, the degree of success of vegetation reestablishment was measured in terms of total weight of aboveground biomass and total percent density of ground cover consisting of plant basal area and accumulated litter. Both of these measures are compatible with the legislative constraints under which mine operators must evaluate reclamation success.

With these constraints in mind and exceedingly strong agency pressures for at least an interim, but "immediate," process for evaluating proposed revegetation actions on areas to be surface mined, a study of existing mine revegetation efforts in the interior West was undertaken. The planned strategy was to provide information on forage production and cover for unmined areas to define undisturbed site potentials, and to provide similar information for comparable surface-mined sites to measure the effectiveness of vegetative rehabilitation treatments applied to date. Those combinations of treatments applied to mined sites and producing forage and cover conditions at least equivalent to the potentials on associated undisturbed sites would then be considered satisfactory for the legislative objectives above.

During the growing seasons of 1976 and 1977, data were obtained from 28 of the 34 major coal surface mines then located throughout the surface-minable coal areas of the West. These data provide information that describes important climatic features, physical and biological characteristics of each site, treatment measures employed to effect revegetation, the age of the planting on each revegetated area, and amounts of forage and ground cover density developed by both native and introduced types of vegetation on these areas. Similar information, except for the age of the vegetation, was also obtained for unmined areas near each mine that had been long-undisturbed and were characterized by predominantly native vegetation.

Information about general climatic features was obtained from tabulations of State climatic data and consisted of total annual precipitation, growing season precipitation, and length of the frost-free growing season. Climatic information of significance appears on the maps of appendix B.

Data concerned with site-specific physical and biological factors were obtained from 176 100-foot transects selected to be representative of the mined and adjacent unmined study areas. Measurements included the aspect, slope steepness, and elevation of each transect. Soil samples from the unmined areas and spoil samples from the mined and revegetated areas were obtained to a depth of 8 inches (20 cm) below the ground surface and were analyzed for texture, conductivity, nitrate nitrogen, phosphorus, potassium, sodium, calcium, magnesium, acidity (pH), sodium adsorption ratio, and saturation percentage.

Along each study transect, fifty 1-ft^2 (0.1 m^2) plots were located randomly for use in determining species composition, aboveground biomass or forage production, and plant cover density. All current growth of perennial plants within these plots was clipped to a height of one-half inch (1.27 cm) above ground, bagged by species, oven-dried for 24 hours, and weighed.

The age of each revegetated area, expressed as number of years since it was planted, and information concerning the treatments applied during and subsequent to its establishment were obtained through consultation with reclamation personnel employed at each of the mines. These treatments reflected differences in tillage, seeding methods, topsoiling, fertilizing, supplemental irrigation, mulching, and time of seeding.

All of the data obtained from 176 transects on the 28 mines studied made up the information base available for analyses.

DATA AND INFORMATION ANALYSES

Six series of analyses were made. These analyses followed multiple regression strategies for estimating forage production and plant cover density as functions of climatic components, growing medium characteristics, and revegetation treatment alternatives. The simple linear effects of independent variables on forage production and cover density were screened statistically in all combinations as a means of isolating the stronger variables for use in synthesizing final models.

Forage Production Model for Unmined Areas

Eighty-three of the 176 transects sampled during this investigation were located on unmined and otherwise long-undisturbed areas adjacent to each of the 28 mines studied. For these areas, annual precipitation amount and growing season length each added significantly ($Pr \leq 0.005$) to the regression for forage production. Soil potassium content, while not adding significantly to the regression after fitting precipitation and growing seasons, did display unusual strength in the short-to-medium length growing season and medium-to-high precipitation range; so it was retained in the model.

Strong interactions, not likely to be well represented by the simple linear additive effects initially screened, were expected to exist among these variables. Accordingly, attention was focused on the interactive effects of these three variables on forage production. Forage production was expected to increase upward concavely with increasing precipitation, to reach a peak somewhere within the broad range of growing season lengths encountered, and to increase with increasing amounts of potassium in the soil. The interactive effects of these variables were modeled under the constraints of expectation, following Jensen and Homeyer (1970, 1971) and Jensen (1973, 1976, 1979). More expressly, expected trends were adjusted to the partitioned data graphically, coordinated to arrive at the interactive relation, and, simultaneously, formulated mathematically. The resulting model was adjusted to the unmined-transect source data ($n = 83$) by least squares (zero intercept) and, under the circumstances of derivation, can only be represented as a reasonably strong hypothesis for the relation at hand. Validation and/or model improvement must be left to future studies.

The effects of precipitation, growing season, and soil potassium on forage production, as expressed by this model, are shown in figure 1. (See equation 1, appendix A.) As might be expected, figure 1 shows that low precipitation is limiting to plant growth, regardless of length of growing season (GS) or level of potassium (K). In semiarid areas of Arizona and New Mexico where precipitation (PR) varies between 5 and 10 inches (13 and 25 cm) and GS is generally in excess of 120 days, production averaged from only 100 to 250 lb/acre (112 to 280 kg/ha) on undisturbed sites.

With PR in the 10- to 15-inch (25- to 38-cm) range and GS varying from perhaps 60 to 130 days, typical of Wyoming and Montana mining sites, production generally ranged from 250 to 1,600 lb/acre (280 to 1 793 kg/ha) in the presence of relatively high K levels (260 p/m). Lesser amounts of K (150 p/m) were associated with a production drop of 100 to 300 lb/acre (112 to 336 kg/ha) within the 60- to 95-day range in GS.

North Dakota mining sites were in a slightly higher PR zone (16 to 17 inches [41 to 43 cm]) and had moderately long growing seasons (113 to 129 days). Production estimates for this region of the model were heavily affected by the more copious Wyoming and Montana data and only reached the 800- to 900-lb/acre (897- to 1 009-kg/ha) range, about 300 to 400 lb/acre (336 to 448 kg/ha) less than the average of the few observations available from the undisturbed North Dakota sites. This fact, along with the relatively high productivity rates generally accredited to the northern Great Plains, suggests the need for stronger data from that area. Note that the potassium effect here was not detectable at GS > 100 days.

A few higher elevation (7,000 to 8,000 ft [2 134 to 2 438 m]) mine sites with precipitation in the 16- to 23-inch (41- to 58-cm) range and shorter (50 to 81 days) growing seasons were sampled in northwestern Colorado. Production is generally greater there, ranging from about 1,600 to 2,100 lb/acre (1 793 to 2 354 kg/ha) for K ≥ 260 p/m, dropping 300 to 500 lb/acre (336 to 560 kg/ha) for K ≤ 150 p/m.

As a whole, this model provides our best estimates of minimum production requirements or standards against which the success of planned revegetation efforts on areas to be mined can be evaluated.

Examples of estimates of forage production made from the equation of this model for selected values of precipitation, growing season, and soil potassium are presented in table 1 to demonstrate the output format from the user-oriented computer program for this model, which is shown in appendix A.

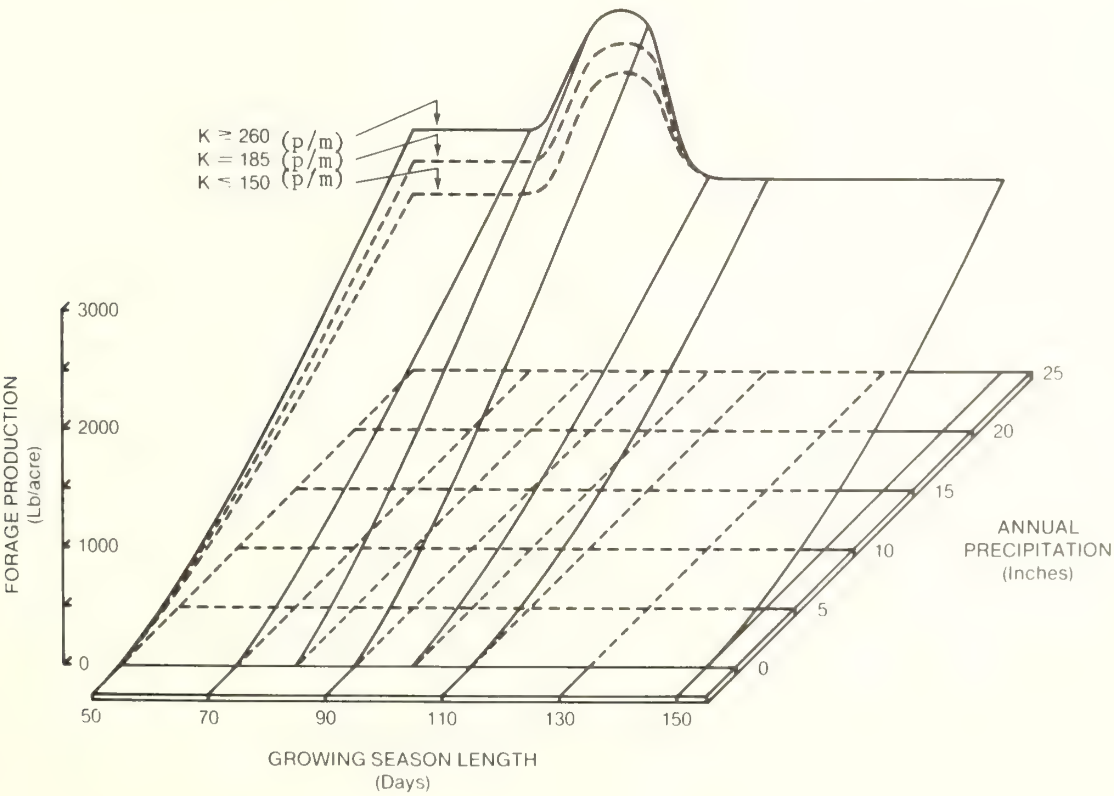

Figure 1.—Effects of annual precipitation, growing season length, and soil potassium content on forage production of unmined sites on surface mineable coal lands.

Table 1.—Effects of annual precipitation, growing season length, and soil potassium content on forage production of unmined sites on surface mineable coal lands (lbs/acre)

NO POTASSIUM

DAYS OF GROWING SEASON	INCHES PRECIPITATION 5	15	25
50	155.	725.	1485.
85	333.	1313.	2487.
120	90.	644.	1608.

200 PARTS/MILLION POTASSIUM

DAYS OF GROWING SEASON	INCHES PRECIPITATION 5	15	25
50	198.	927.	1897.
85	388.	1531.	2899.
120	90.	644.	1608.

400 PARTS/MILLION POTASSIUM

DAYS OF GROWING SEASON	INCHES PRECIPITATION 5	15	25
50	211.	984.	2015.
85	404.	1593.	3017.
120	90.	644.	1608.

Plant Cover Density Model for Unmined Areas

Procedures for modeling the density of plant cover on unmined areas were similar to those used for forage production. Screening of linear effects again revealed that annual precipitation and length of growing season were strong variables ($Pr \leq 0.025$) and that potassium showed strength at short-to-medium length growing seasons and medium-to-high precipitation ranges. An interactive model involving these variables was generated and fitted to data from the 83 transects located on unmined areas. Relations between plant cover density and annual precipitation, growing season length, and soil potassium content are illustrated by the response surfaces in figure 2. (See equation 2, appendix A.) As expected, this model shows that low PR is limiting to plant cover density development. This is accentuated somewhat for the generally longer and hotter growing seasons of the semiarid Southwest where, with 5 to 10 inches (13 to 25 cm) of PR, plant cover density ranges from near zero to 25 percent.

In Wyoming and Montana, at 10 to 15 inches (25 to 38 cm) of PR and 60- to 120-day growing seasons, density of cover varies from 30 to 85 percent. This full range apparently occurs in response to PR alone, where growing seasons are in excess of 100 days. In northwestern Colorado at higher elevations (7,000 to 8,000 ft [2 134 to 2 438 m]), with fewer GS (50 to 81) days and relatively high K levels (≥ 260 p/m), the density of plant cover ranges from 75 to 85 percent. A decrease of 60 p/m of potassium occasions a reduction of about 10 percent in cover here.

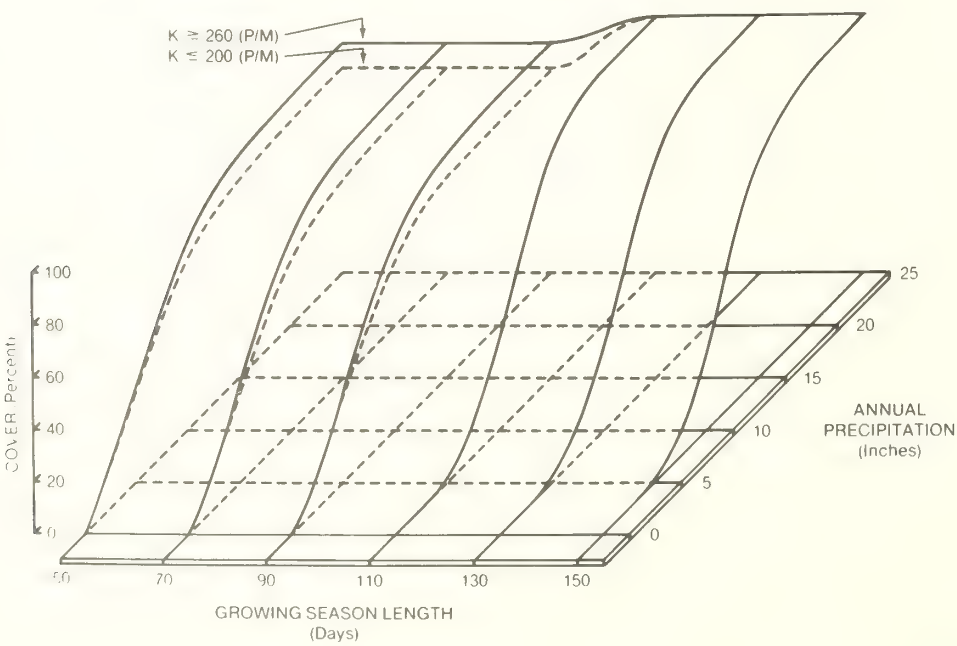

Figure 2.—Effects of annual precipitation, growing season length, and soil potassium content on vegetative cover density of unmined sites on surface mineable coal lands.

Table 2.—Effects of annual precipitation, growing season length, and soil potassium content on vetetative cover density of unmined sites on surface mineable coal lands (percent)

	NO POTASSIUM			200 PARTS/MILLION POTASSIUM			400 PARTS/MILLION POTASSIUM		
DAYS OF GROWING SEASON	INCHES PRECIPITATION 5	15	25	5	15	25	5	15	25
50	34.	76.	78.	34.	76.	78.	37.	85.	87.
85	34.	76.	78.	34.	76.	78.	37.	85.	87.
120	1.	83.	98.	1.	83.	98.	1.	83.	98.

At a PR of about 15 inches (38 cm), GS<110, and K $\geq$ 260 p/m, the maximum density potential of plant cover appears to be about 85 percent, with a drop to 75 percent at lower K levels ($\leq$ 200 p/m). For GS $\geq$ 110 days, an almost full cover of 98 percent is reached at PR > 18 inches (46 cm). These conditions are typical of the North Dakota area. Under these conditions, potassium did not seem to be a limiting factor.

The equation for this model was used to estimate plant cover densities for selected values of annual precipitation, growing season length, and soil potassium content. Examples of these estimated plant cover densities are shown in table 2; they demonstrate the output format from the user-oriented computer program for this model, which is shown in appendix A.

This model provides estimates of plant cover density on unmined areas. These estimates can be considered as minimum requirements or standards against which the success of revegetation efforts on mined areas can be evaluated.

Forage Production Models for Mined Areas

Two models were developed to estimate forage production to be expected from revegetation of surface-mined areas. One model was generated to estimate the amounts of forage produced on revegetated areas dominated by native plant species. Another was developed to provide similar estimates where revegetated areas are dominated by introduced plant species. Each model is composed of an interactive base and a group of additive effects.

The age of the planting, the climatic components of annual precipitation and growing season length, and the potassium content of spoils (fitted in that order) added significantly (Pr $\leq$ 0.10) to linear regressions for forage production from both native and introduced vegetation. Subsequently, attention was focused on interactive relations between forage production and the three independent variables: age, annual precipitation, and growing season length. Forage production was expected to be convex upward over age, reaching a maximum at some point in time; to be concave upward over precipitation; and to reach a peak somewhere within the broad range of growing season lengths encountered. Expected trends were adjusted to the partitioned data graphically, coordinated to arrive at the interactive relation, and, simultaneously, formulated mathematically. The resulting model was adjusted to the mined-transect source data for native (n = 44) and introduced (n = 33) species. Under the circumstances of derivation, these models can only be represented as reasonably strong hypotheses for the relations at hand. Model validation and/or improvement must be left to future studies. The interactive portion of this model for forage production from native plant species is illustrated by the response surfaces in figure 3. (See equation 3, appendix A.)

Production for this, the interactive portion of the model, appeared to reach an upper asymptote at age-of-planting = 5 years. Production trends, as yet unadjusted for the effects of potassium, sodium, pH, and vegetative rehabilitation treatments, still closely reflected the shape of the PR effect in the production model for unmined areas and the optimum at 85 days for the GS effect still existed.

A comparable model for estimating forage production on revegetated areas dominated by introduced plant specis is identical in shape to the model for native plant species. These models of well-defined interactive effects were refitted to their respective data sets and were adopted as fixed prediction bases. The residuals from these bases were then expressed as linear additive effects of the somewhat weaker continuous variables, potassium, sodium, pH, and of the discrete (present or absent, in this case) revegetation treatment variables, tilling, seeding method, topsoiling, fertilizing, supplemental irrigation, mulching, and seeding time. The sum of the interactive and linear additive effects constitutes the estimate of production.

Selected values of annual precipitation and growing season length were utilized in the equation for the interactive model shown in figure 3. The output from this equation together with the additive effects of selected values of soil potassium, sodium, and pH content, and those of the seven revegetation treatments, provided estimates of the amounts of forage produced at 5 years of age on surface-mined areas revegetated with predominantly native species. Age of 5 years was selected for these estimates because the model revealed that biomass production from revegetation of western coal surface mines tends to reach peak development in about 5 years. Examples of these forage production estimates are presented in table 3 to demonstrate the output format from the user-oriented computer program for this model, which is shown in appendix A.

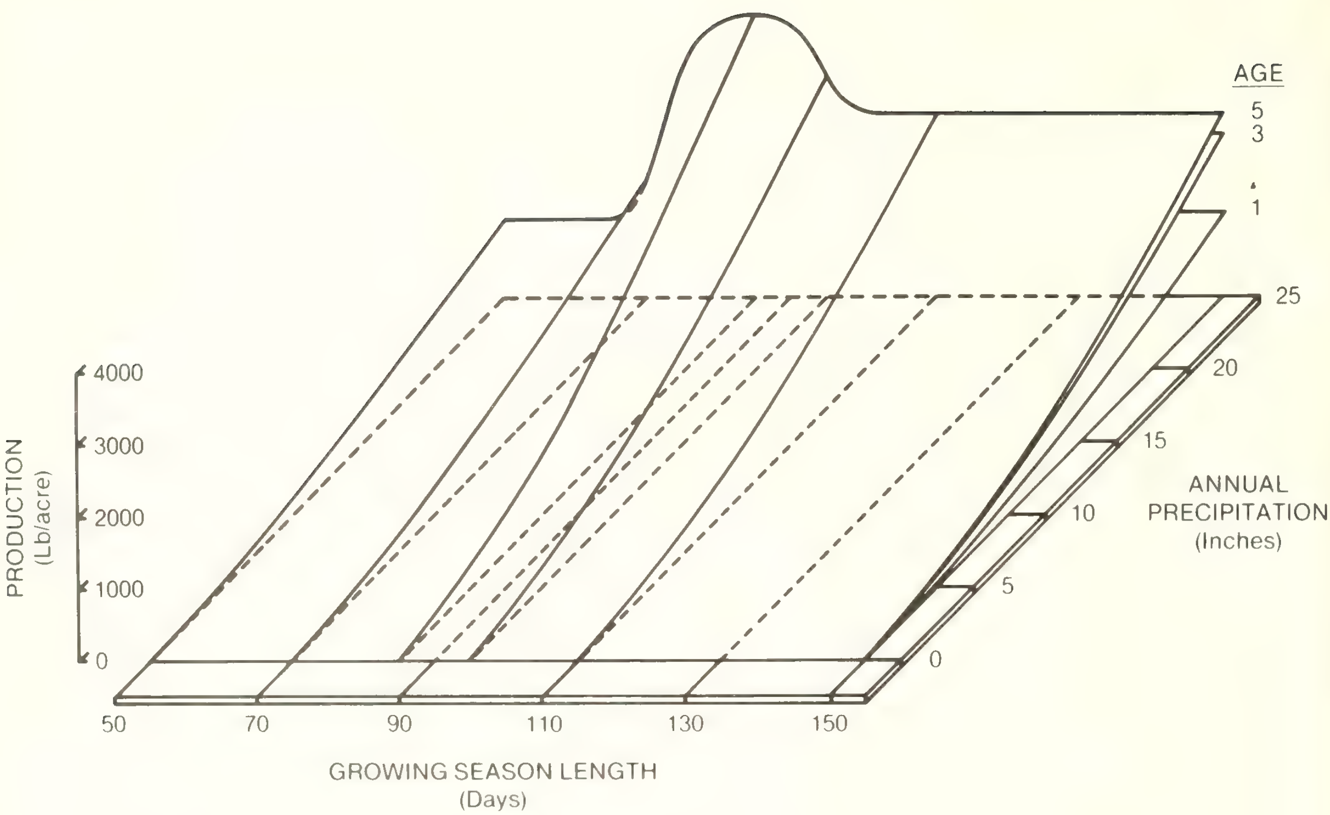

Figure 3.—Effects of annual precipitation, growing season length, and age of planting on forage production of mined and revegetated sites on coal surface mines.

Information in this sample portion of model output is divided into three blocks, each of which represents a different level of annual precipitation. In order from left to right, these levels are 5 inches (13 cm), 15 inches (38 cm), and 25 inches (64 cm). All remaining variables are identical for each of the three blocks. The growing season length is 85 days. The soil potassium content is 200 p/m. The soil sodium content (Na) is 300 meq/liter and the soil pH is 8. Each of the three blocks of the table consists of eight columns, seven of which are occupied by data from the seven revegetation treatments. The last column in each block records the dry weight of forage produced in the presence of revegetation treatments checked with the letter X. Tillage of the soil (TIL), consisting of ripping, disking, or plowing prior to seeding, is shown with an X. A blank indicates that the soil was not tilled. Drilling as a seeding method (SM) is indicated by an X, whereas broadcast seeding is represented by a blank. Addition of topsoil prior to seeding (TPS) is indicated by an X; a blank shows that no topsoil was added. An X indicates that fertilizer (FER) was added; a blank indicates that it was not. Supplemental irrigation (IRR) is indicated by an X; no irrigation is represented by a blank. Mulching (MUL) is indicated by an X, and no mulching is a blank. An X for seeding time (ST) indicates fall seeding, whereas a blank represents spring seeding.

Forage production values such as those for native species in table 3 can be compared with the appropriate forage production values for unmined areas such as those in table 1. Production values from mined and revegetated areas after 5 years of growth that are equal to or greater than the production values from similar unmined areas denote successful revegetation in relation to production of vegetation on the undisturbed areas which is assumed to reflect ecological potentials.

Similarly, estimated amounts of forage produced were generated from the interactive and additive components of the model for forage production of introduced species. These production values are 12.5 percent higher than those of native species. This is not surprising since plant species introduced for range improvement in the West generally have been selected for their exceptional hardiness and productivity characteristics.

Table 3.—Effects of climatic factors, spoil properties, and revegetation treatments on forage production of mined sites revegetated predominantly with native species (lbs/acre)

MINED AREAS
NATIVE SPECIES PRODUCTION

GS 85, K 200, NA 300, PH 8 (the same in all three panels)

TIL	SM	TPS	FER	IRR	MUL	ST	PR 5 PROD PER ACRE	PR 15 PROD PER ACRE	PR 25 PROD PER ACRE
							72	1469	3605
X							85	1483	3618
	X						413	1810	3946
		X					0	1386	3522
			X				440	1838	3973
				X			107	1504	3640
					X		0	1292	3427
						X	406	1804	3939
X	X						426	1823	3959
X		X					2	1400	3535
X			X				454	1851	3987
X				X			120	1518	3653
X					X		0	1305	3441
X						X	420	1817	3953
	X	X					329	1727	3862
	X		X				781	2179	4314
	X			X			447	1845	3980
	X				X		235	1633	3768
	X					X	747	2145	4280
		X	X				357	1755	3890
		X		X			24	1421	3557
		X			X		0	1209	3344
		X				X	323	1721	3856
			X	X			475	1873	4008
			X		X		263	1661	3796
			X			X	775	2173 *	4308
				X	X		0	1327	3462
				X		X	441	1839	3974
					X	X	229	1626	3762
X	X	X					343	1740	3876
X	X		X				795	2192	4328
X	X			X			461	1858	3994
X	X				X		248	1646	3781
X	X					X	760	2158	4293
X		X	X				371	1768	3904
X		X		X			37	1435	3570
X		X			X		0	1222	3357
X		X				X	337	1734	3870
X			X	X			489	1886	4022
X			X		X		276	1674	3809
X			X			X	788	2186 *	4321
X				X	X		0	1340	3475
X				X		X	455	1852	3988
X					X	X	242	1640	3775
	X	X	X				698	2096	4231
	X	X		X			364	1762	3897
	X	X			X		152	1550	3685
	X	X				X	664	2052	4197
	X		X	X			816	2214 *	4349

Plant Cover Density Models for Mined Areas

Procedures for modeling the density of plant cover on mined areas were similar to those used to model forage production. Two interactive models were generated, one for revegetated areas predominantly characterized by native species and the other for areas dominated by introduced species. The models relate plant cover density to the amount of annual precipitation, age of the planting, and length of the growing season. These relations for mined areas revegetated with native species are illustrated by the response surfaces shown in figure 4. (See equation 4, appendix A.)

Plant cover density increased with increasing amounts of annual precipitation and with increasing age of vegetation up to about 5 years. It was also greatest at about 85 days, an intermediate growing season length. Selected values of annual precipitation and of growing season length were used in the equation for this interactive model. These, along with the additive effects of selected values of soil potassium, sodium, and pH content and of the revegetation treatments, permitted estimates of the plant cover densities expected at 5 years of age on surface-mined areas revegetated with predominantly native species.

Examples of these plant cover density estimates are presented in table 4 to demonstrate the output format from the user-oriented computer program for the model, which is shown in appendix A.

Plant cover density values, such as those in table 4, can be compared with the appropriate cover density values for unmined areas, such as those in table 2. Plant cover density values (age = 5 years) from mined and revegetated areas that are equal to or greater than those from similar unmined areas denote successful revegetation. Plant cover density development on these unmined areas is assumed to reflect ecological potentials.

Similarly, estimated plant cover density values were generated from the interactive and additive components of the plant cover density model for introduced species. These density values are 8.8 percent lower than those of native species. While introduced species are superior in producing forage native species appear able to provide better protective ground cover. Thus, both kinds of plants possess characteristics that enable them to meet requirements of the Surface Mining Control and Reclamation Act by "establishing a diverse, effective, and permanent vegetative cover" on revegetated coal mine spoils in the Western United States.

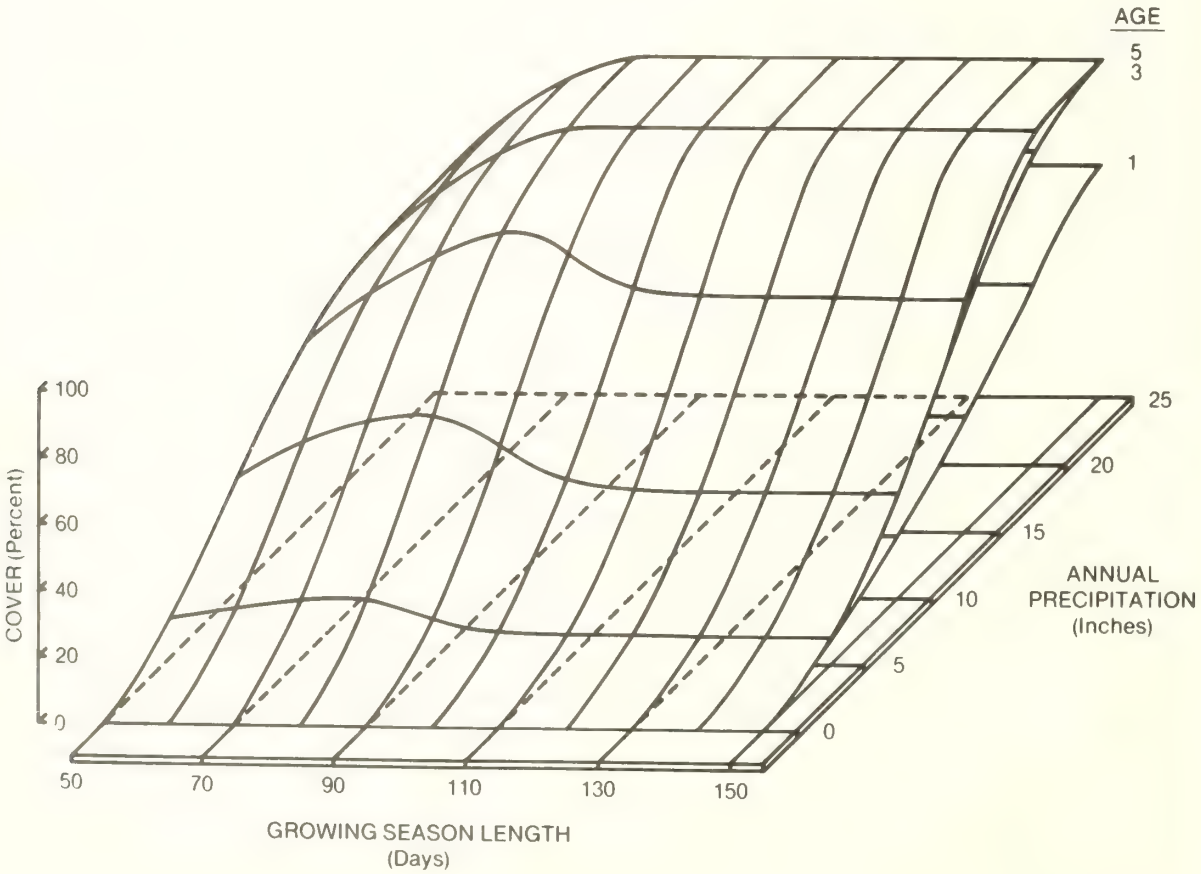

Figure 4.—Effects of annual precipitation, growing season length, and age of planting on vegetative cover density of mined and revegetated sites on coal surface mines.

Table 4.—Effects of climatic factors, spoil properties, and revegetation treatments on vegetative cover density of mined sites revegetated predominantly with native species (percent)

MINED AREAS
NATIVE SPECIES COVER

PR 5 GS 85 K 200 NA 300 PH 8

TIL	SM	TPS	FER	IRR	MUL	ST	% COVER
							7
X							3
	X						5
		X					13
			X				18
				X			7
					X		22
						X	1
X	X						1
X		X					9
X			X				14
X				X			4
X					X		18
X						X	0
	X	X					11
	X		X				16
	X			X			6
	X				X		20
	X					X	0
		X	X				24
		X		X			13
		X			X		28
		X				X	7
			X	X			19
			X		X		33
			X			X	12
				X	X		23
				X		X	2
					X	X	16
X	X	X					7
X	X		X				12
X	X			X			2
X	X				X		16
X	X					X	0
X		X	X				20
X		X		X			10
X		X			X		24
X		X				X	3
X			X	X			15
X			X		X		29
X			X			X	9
X				X	X		19
X				X		X	0
X					X	X	12
	X	X	X				22
	X	X		X			12
	X	X			X		26
	X	X				X	5
	X		X	X			17

PR 15 GS 85 K 200 NA 300 PH 8

TIL	SM	TPS	FER	IRR	MUL	ST	% COVER
							76
X							72
	X						75
		X					82
			X				88
				X			77
					X		92
						X	71
X	X						71
X		X					78
X			X				84
X				X			73
X					X		88
X						X	67
	X	X					81
	X		X				86
	X			X			75
	X				X		90
	X					X	69
		X	X				94
		X		X			83
		X			X		98
		X				X	77
			X	X			88
			X		X		100
			X			X	82
				X	X		92
				X		X	71
					X	X	86
X	X	X					77
X	X		X				82
X	X			X			71
X	X				X		66
X	X					X	65
X		X	X				90
X		X		X			79
X		X			X		94
X		X				X	73
X			X	X			84
X			X		X		99
X			X			X	78
X				X	X		88
X				X		X	67
X					X	X	82
	X	X	X				92
	X	X		X			81
	X	X			X		96
	X	X				X	75
	X		X	X			86

PR 25 GS 85 K 200 NA 300 PH 8

TIL	SM	TPS	FER	IRR	MUL	ST	% COVER
							94
X							90
	X						92
		X					100
			X				100
				X			95
					X		100
						X	89
X	X						88
X		X					96
X			X				100
X				X			91
X					X		100
X						X	85
	X	X					98
	X		X				100
	X			X			93
	X				X		100
	X					X	87
		X	X				100
		X		X			100
		X			X		100
		X				X	95
			X	X			100
			X		X		100
			X			X	100
				X	X		100
				X		X	89
					X	X	100
X	X	X					94
X	X		X				100
X	X			X			89
X	X				X		100
X	X					X	83
X		X	X				100
X		X		X			97
X		X			X		100
X		X				X	91
X			X	X			100
X			X		X		100
X			X			X	96
X				X	X		100
X				X		X	85
X					X	X	100
	X	X	X				100
	X	X		X			99
	X	X			X		100
	X	X				X	93
	X		X	X			100

APPLICATION

The outputs from this research include two regression models for **unmined** (undisturbed) areas, one for use in estimating forage production weights and the other for estimating vegetative cover densities. Also included are four regression models for **mined** areas. Two models are for use in estimating forage production weights, one where native plants predominate, the other where introduced plant species are dominant. The other two models are for use in estimating vegetative cover densities of native and of introduced vegetation.

Each of these six models is expressed as an algebraic equation in appendix A. Following each of these equations are FORTRAN IV computer programs to facilitate computer solutions for pertinent combinations of the different levels of the independent variables involved and, as appropriate, for native and introduced species. The values contained in tables 1, 2, 3, and 4 are sample outputs from these FORTRAN programs.

Another output from this research consists of two multicolored maps (scale 1:1,000,000) that depict the following information for the surface mineable coal areas of the West, as well as for most of the intervening areas (appendix B, inside back cover).

1. Annual precipitation (inches);
2. Growing season length (days);
3. Natural vegetation types and their identification numbers (Küchler 1964);
4. Soil associations and their identification numbers (Aandahl 1972; Cipra and others 1977; Jay and others 1975; Maker and others 1974; Southard 1973; Wilson and others 1975; and Young and Singleton 1977).

These maps provide estimates of precipitation and growing season length and identify the soil association and natural vegetation type for any location on surface-mineable coal areas of the West.

Here are instructions covering use of the maps, equations, and tables in order to estimate the average degree of revegetation success on any of these surface-mineable coal areas.

1. For any selected location on either of the maps determine values of precipitation and growing season length and identify the soil association and vegetation type by numbers. The soil association numbers are those contained either in Soils of the Great Plains (Aandahl 1972) or in individual State soil description publications (Cipra and others 1977; Jay and others 1975; Maker and others 1974; Southard 1973; Wilson and others 1975; and Young and Singleton 1977), which are referenced in the Publications Cited section. These publications contain information concerning the chemical and physical characteristics of the soil associations. The vegetation type numbers are contained in Küchler's 1964 map of "The Potential Natural Vegetation of the Conterminous United States." This map identifies the dominant native species that make up each vegetation type. Such identification provides ecological guides to selection of plant species adapted for revegetation purposes.
2. Use the values of annual precipitation, growing season length, and soil potassium content in equation 1, appendix A for unmined areas to calculate forage production in pounds per acre. Similarly, the values of these factors can be used in equation 2, appendix A to calculate cover density in percent. These values are considered to define the ecological potential for producing forage and developing cover density at this location. If published information concerning the chemical characteristics of the particular soil association under consideration is not available, then soil sampling may be necessary to obtain site specific data on the soil potassium content.
3. Depending upon whether revegetation of **mined areas** or planned revegetation of **areas to be mined** is with native or with introduced types of vegetation, enter the appropriate version of the **mined areas** interactive component equation (equation 3, appendix A) with the same precipitation and growing season values that were used in the unmined area equations. Calculate the interactive effects of these factors on the estimated pounds per acre of forage produced at age 5 years.
4. Enter the appropriate additive component table for forage production (table 1, appendix A). Calculate additional effects on forage production of spoil potassium, sodium, and pH conditions encountered or expected, as well as additional effects of the seven revegetation treatments indicated. In the event that previous mine spoil analyses are not available or do not provide sufficient information on potassium, sodium, and pH levels, spoil sampling may be necessary to obtain specific on-site values of these factors.
5. Add the pounds per acre of forage production calculated from the interactive component equation to the pounds per acre calculated from the additive component table. These values are the estimated forage production amounts achievable under the climatic, spoil, and revegetation treatment conditions encountered.
6. Similar calculations of achievable plant cover densities can be made utilizing the climatic, spoil, and revegetation treatment factors in the interactive component equation (equation 4, appendix A) and additive component table (table 2, appendix A) for plant cover density.
7. Select those alternative revegetation treatment combinations that provide forage production weight and plant cover density values equal to or greater than the values from the comparable unmined area equations. These values denote success compared to the ecological standards for existing conditions and they identify the combinations of climatic, spoil, and revegetation treatment conditions needed to achieve such success 5 years after planting.

Following is an example of the use of the maps, tables, and equations to compare estimated forage production weights of predominantly native vegetation on a selected unmined and mined site in eastern Montana.

1. From the maps, it is determined that the average annual precipitation at the selected site is 15 inches (38 cm). The growing season length is 85 days. The soil association is Aandahl's number 117, which is moderately low in potassium (less than 200 p/m), high in sodium (more than 300 meq/L), and high in pH (about 8). The vegetation type is Küchler's number 6, grassland-sagebrush, which contains a number of highly adapted and suitable grass and shrub species for revegetation.

2. Utilizing this information, enter table 1 in the center section: 200 p/m of potassium, 15 inches (38 cm) of precipitation, and 85 days of growing season. This combination of conditions results in a tabulated estimate of 1,531 pounds per acre (1 716 kg/ha) of native vegetation weight produced on the unmined site, the ecological potential for this site. This same value, 1,531 pounds per acre can be obtained by solving equation 1, appendix A as follows:

$$\begin{aligned} N &= 1.8 - 0.56 * e^{-0.01770} \\ &= 1.8 - 0.56 * 0.9825 = 1.250 \end{aligned}$$

$$\begin{aligned} YPFL &= 1{,}570 + 1{,}060 * e^{-0.00056} \\ &= 1{,}570 + 1{,}060 * 0.9994 = 2{,}629.4 \end{aligned}$$

$$\begin{aligned} YP1 &= YPFL + 560 * e^{-0.25025} \\ &= 2{,}629.4 + 560 * 0.7786 = 3{,}065.4 \end{aligned}$$

$$\begin{aligned} PRODUCTION &= \frac{3{,}065.4}{(25)^{1.25}} * (15)^{1.25} * 0.94584 \\ &= 1{,}531 \text{ pounds/acre} \end{aligned}$$

3. Further utilizing the information obtained from the maps and the cited soil reference (Aandahl 1972), enter table 3 in the center section. Here, the native vegetation production weight estimates are for 15 inches (38 cm) of precipitation, 85 days of growing season, 200 p/m of potassium, 300 meq/liter of sodium, and pH of 8—the conditions encountered at this site. This combination of conditions, together with the various revegetation treatment combinations indicated in the table, results in a number of production weight estimates in excess of 1,531 pounds per acre (1 716 kg/ha) when the vegetation on the mined areas is 5 years old. The highest production weight in that portion of the total table represented by table 3—2,214 lb/acre (2 482 kg/ha)—can be achieved by selecting a combination of treatments that includes drilling seed in the spring, fertilizing the area with a well-balanced N—P—K fertilizer, and irrigating. Very nearly the same production level (2,186 lb/acre or 2 450 kg/ha) can be achieved by tilling, drilling in the fall, and fertilizing without irrigation. Almost as much production (2,173 lb/acre or 2 436 kg/ha) is obtainable with much less effort and expense simply by drilling and fertilizing in the fall without either tillage or irrigation.

These estimates of forage production weight can be obtained by solving equation 3, appendix A and adding the appropriate elements from the additive component table (table 1, appendix A). This solution for the maximum weight of 2,214 lb/acre (2 482 kg/ha) is as follows:

a. **Equation 3**

$$\begin{aligned} PRODUCTION &= 0.0061896 * YPPR * YPGS \\ &\quad * (PR)^{1.6} * 1.04368 \end{aligned}$$

$$YPPR = e^{-0.00510} = 0.99491$$

$$\begin{aligned} YPGS &= 940 + 2{,}510 * e^{-0} \\ &= 940 + 2{,}510 * 1 = 3{,}450 \end{aligned}$$

$$\begin{aligned} PRODUCTION &= 0.0061896 * 0.99491 * 3{,}450 \\ &\quad * (15)^{1.6} * 1.04368 \\ &= 1{,}688 \text{ pounds/acre} \end{aligned}$$

b. **Additive components (native vegetation)**

Soil potassium (K)	200 * 5.4	=	1,080
Soil sodium (Na)	300 * (−0.088)	=	−26
Soil acidity (pH)	8 * 117.9	=	944
Intercept			−2,216
Seed drilled			341
Fertilizer			369
Irrigation			35
Spring seeding			0
Additive components total			526 pounds/acre
Total production (1,688 + 526)			2,214 pounds/acre

c. These forage production weight values—up to 2,214 pounds per acre (2 482 kg/ha) on revegetated mined areas compared to only 1,531 pounds per acre (1 716 kg/ha) on similar but unmined sites—indicate that successful revegetation can be achieved on mined sites characterized by the climatic, soil, and treatment conditions specified in this example. Still unanswered are questions concerning the permanency of production weights of such magnitude in the absence of further fertilization or of what the land management requirements are to maintain such production. Examination of the complete computer-produced tables leads one to conclude, however, that revegetation treatment alternatives are available to produce forage weights (and cover densities) which, 5 years after establishment, are greater than the ecological potentials of most western coal mine sites.

4. The algebraic specifications for the six models are presented in appendix A as equations. Immediately following each is an associated FORTRAN IV computer program designed to produce tables like the text examples (tables 1-4). Note that these programs are designed to run on IBM or IBM-compatible systems such as the Amdahl 470V/6-II. Minor program changes, such as "read" and "write" instructions and a substitute for the standard IBM ERRSET subroutine, may have to be made before they will run on alternative systems.

In the programs for mined areas, three groups of preselected values of PR, GS, K, Na, and pH (in this sequence) are used in statement 003 as a major control for program output. The values are: 5, 50, 0, 0, 4; 15, 85, 200, 150, 6; and 25, 120, 400, 300, 8. These can be changed to accommodate alternative output needs, but must be within the limits of use specified for each variable and algebraic model. The output format for vegetative treatments is considered fixed and should not be altered.

The program for unmined areas produces both forage production and cover percent estimates. Only three variables control the output here, PR, GS, and K. Three preselected values of each appear in the program as follows:

Statement 0008, where K = 50, 120, 35. K represents GS here and the statement is interpreted to mean that

GS levels start at 50, and are incremented by 35 until the maximum of 120 is reached. Thus, GS—levels = 50, 85, and 120.

Statement 0010, where LL = 1, 401, 200. LL represents K and the statement is interpreted as in 0008, so that K levels are 1, 201, and 401. "One" has been added to the desired values of 0, 200, and 400 to accommodate a programming limitation at zero. One is subtracted (in statement 0011) before model computations are begun so that the final output is for K levels of 0, 200, and 400.

Statement 0012, where M = 5, 25, 10. M represents PR and the statement is interpreted as in 0008, so that the PR levels are 5, 15, and 25.

The levels of these variables can be changed to meet alternative output needs but, again, must be within the limits specified for each variable and algebraic model.

Neither pagination nor indexing is provided in these programs. It is suggested that users add such provisions for convenience in application of the many tables generated (243 tables here).

DISCUSSION

The primary objectives of this investigation were to develop capabilities for estimating the degree of revegetation success to be expected under a wide variety of climatic conditions, soil and spoil properties, and revegetation treatments utilizing site-specific revegetation data and information from most of the coal surface mines in the interior West. The more important study developments are these:

- A strong conceptual framework for evaluating the success of proposed vegetative rehabilitation efforts on areas to be surface mined.
- Site-specific maps have been developed to provide precipitation, growing season length, soil, and vegetation type information, critical to the evaluation system.
- Results of most existing surface-mine rehabilitation efforts in the interior West through 1976 were surveyed as a basis for evaluating revegetation success.
- Interim predictors (models) were developed, based on these survey data, for forage production and cover density potentials on:
  - Undisturbed sites adjacent to the study mines.
  - Mined areas with various combinations of planting and postplanting methods and treatments designed to enhance the total rehabilitation effort for:
    - Native species;
    - Introduced species.

This investigation shows that practical criteria for measuring revegetation success, namely, the amount of forage produced and the density of plant cover developed, are affected significantly by at least two major climatic factors that are not readily susceptible to alteration (PR and GS); by three properties of spoil materials that are subject to limited modification through management (K, Na, and pH). Revegetation success is also influenced by seven revegetation treatments, each of which provides at least two management alternatives, and by the age of the vegetation. These characteristics account for about one-half to three-fourths of the total variance in forage production and plant cover density in the prediction models (table 3, appendix A).

It is emphasized here that the models should be used with considerable discretion since the source data, while the best available, is weak in many respects. First, there were only 34 mines in the entire area covered by this study where revegetation was even attempted. The kinds of revegetation efforts, insofar as specific treatments or combinations of treatments are concerned, differ between mines and, in many cases, even between years on the same mine. For example, seeds of native species may be broadcast in the fall on the spoils of one mine, whereas seeds of introduced species may be drilled into the soils of another mine in the spring. In each case, the combinations of other treatments, such as topsoiling, tilling, mulching, or fertilizing, might be substantially different. Of the large number of possible treatment combinations, relatively few exist on the 28 mines studied, and the comparative revegetation success of those that do exist is confounded by mine-to-mine differences in climatic and growing media environment. Further, "treatments" cannot be considered to be standardized. For example, the depth and quality of topsoil (when added) are almost certain to differ between mines. Fertilizer composition and rates and times of application are largely unknown. Also unknown are rates of seed application, depths of drilled seed, the quality of seed, the mix of species seeded, the depth of tillage, the kinds and amounts of mulch applied, and supplemental irrigation amounts and frequencies. At the time of this study, about half of the revegetation efforts were no more than 2 years old; so, on the mines involved, seeded plants had not had time to respond fully to the growing environment and revegetation treatments. Revegetation success, of course, is strongly affected by the particular amount and timing of precipitation during the year or period of years involved in the revegetation effort.

It seems certain that the interest in western coal development and associated environmental controls will continue for a number of years. Under these circumstances and because of the low-order quantitative information available on the success of spoil rehabilitation efforts, we recommend *strongly* that extensive, well-planned experimentation be underwritten by the agencies requiring this information. Although such research is now underway in the Forest Service, it is of limited scope and cannot fully meet all of the management needs specified.

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APPENDIX A CONTENTS

APPENDIX A—EQUATIONS AND SUPPLEMENTAL TABLES FOR USE IN ESTIMATING FORAGE PRODUCTION WEIGHTS AND PLANT COVER DENSITIES

The figures and partial tables presented in this paper are useful as an aid in understanding the relations described by the models for estimating forage production weights and plant cover densities. They are not particularly effective, however, as tools for generating such estimates. Needed to estimate useful values of forage production and plant cover density are the equations for the interactive portions of these models (both unmined and mined area models) and the tables for the additive components (mined-area models only). These equations and additive-effect tables follow. Note that the sum of the interactive fixed base and linear residual effects constitutes the estimate of total forage production weight or vegetation cover density. While these models can be solved readily with most pocket calculators, computerized solutions are strongly recommended if production of tables of estimates is the desired end product.

1. Equations for unmined areas

   The models for unmined areas are basically interactive.

   a. Forage production model equation (Equation 1)

$$\widehat{\text{Production}} = \left\{ \frac{YPi}{(25)^N} (PR)^N \right\} * 0.94584$$

$$N = 1.8 - 0.56 * e^{-\left| \frac{\frac{(180 - GS)}{106} - 1}{0.3} \right|^{3.8}}$$

<u>If GS ≤ 87</u>

$$YP1 = YPFL + 560 * e^{-\left| \frac{\frac{K}{450} - 1}{0.6} \right|^{18}}$$

$$YPFL = 1570 + 1060 * e^{-\left| \frac{\frac{GS}{86.6} - 1}{0.12} \right|^{4}}$$

<u>If GS > 87</u>

$$YP2 = 1700 + (YP1^{1/} - 1700) * e^{-\left| \frac{\frac{(180-GS)}{93.4} - 1}{0.09} \right|^{3}}$$

<u>LIMITS</u>

$5 \le PR \le 25$	PR = annual precipitation, inches
$50 \le GS \le 180$	GS = growing season, days
$0 \le K \le 450$	K = potassium, p/m

[1]@ YPFL = 2630

b. Plant cover density model equation (Equation 2)

$$\widehat{\text{Cover}} = YP * \left[\frac{e^{-\left|\frac{\frac{PR}{25} - 1}{(1 - I)}\right|^{5}} - e^{-\left\{\frac{1}{(1 - I)}\right\}^{5}}}{1 - e^{-\left\{\frac{1}{(1 - I)}\right\}^{5}}} \right] * 0.97917$$

$$YP = YPFL + YPAD$$

$$YPFL = 80 + 20 * e^{-\left|\frac{\frac{GS}{180} - 1}{0.46}\right|^{15}}$$

$$YPAD = \left[9 * e^{-\left|\frac{\frac{K}{400} - 1}{0.43}\right|^{15}} \right] * \left[1 - e^{-\left|\frac{\frac{GS}{180} - 1}{0.46}\right|^{15}} \right]$$

$$I = 0.14 + 0.285 * e^{-\left|\frac{\frac{GS}{180} - 1}{0.46}\right|^{15}}$$

LIMITS

$5 \leq PR \leq 25$	PR = annual precipitation, inches
$50 \leq GS \leq 180$	GS = growing season, days
$0 \leq K \leq 450$	K = potassium, p/m

c. FORTRAN IV computer programs for estimating forage production (equation 1) and plant cover density (equation 2)

```
      REAL I,LN
      DIMENSION CLP(9)
      CALL ERRSET (208,256,-1,0)
      PRINT 101
      DO 30 J=1,2
      IF(J.EQ.2) PRINT 100
      PRINT 102
      DO 25 K=50,120,35
      N=0
      DO 20 LL=1,401,200
      L=LL-1
      DO 18 M=5,25,10
      GS=K
      PR=M
      PO=L
      N=N+1
      IF(J.EQ.2) GO TO 26
      I=.14+.285*(EXP(-(ABS((GS/180.-1.)/.46)**15)))
      YPFL=80.+20.*(EXP(-(ABS((GS/180.-1.)/.46)**15)))
      YPA=1.-(EXP(-(ABS((GS/180.-1.)/.46)**15)))
      YPD=9.*(EXP(-(ABS((PO/400.-1.)/.43)**15)))
      YP=YPFL+YPA*YPD
      LN=EXP(-(ABS((PR/25.-1.)/(1.-I))**5))
      RN=EXP(-((1./(1.-I))**5))
      CLP(N)=((LN-RN)/(1.-RN))*YP*.97917
   18 CONTINUE
   20 CONTINUE
      PRINT 103,K,(CLP(II),II=1,3),K,(CLP(II),II=4,6),K,(CLP(II),II=7,9)
   25 CONTINUE
      PRINT 104
      GO TO 30
   26 YN=1.8-.56*(EXP(-(ABS(((180.-GS)/106.-1.)/.3)**3.8)))
      YPFL=1570.+1060.*(EXP(-(ABS((GS/86.6-1.)/.12)**4)))
      YP1=YPFL+560.*(EXP(-(ABS((PO/450.-1.)/.6)**18)))
      IF(GS.GT.86.6) GO TO 28
   27 CLP(N)=((YP1/25.**YN)*PR**YN)*.94584
      GO TO 18
   28 YP1=1700.+(YP1-1700.)*(EXP(-(ABS(((180.-GS)/93.4-1.)/.09)**3)))
      GO TO 27
   30 CONTINUE
      STOP
  100 FORMAT('1',39X,'U N M I N E D   A R E A S'/' ',47X,
     *'F O R A G E'/' ',28X,'P R O D U C T I O N   P O U N D S',
     *'   P E R   A C R E')
  101 FORMAT('-',39X,'U N M I N E D   A R E A S'/' ',47X,
     *'F O R A G E'/' ',34X,'P E R C E N T A G E   O F   C O V E R')
  102 FORMAT('0',7X,'NO POTASSIUM',20X,'200 PARTS/MILLION POTASSIUM',
     *12X,'400 PARTS/MILLION POTASSIUM'/' ',
     *3('+',7('='),'+',17('-'),'+',12X)/' ',
     *3(':DAYS OF:       INCHES       :',12X)/' ',
     *3(':GROWING:  PRECIPITATION  :',12X)/' ',
     *3(': SEASON:   5      15     25 :',12X)/' ',
     *3('+',7('-'),'+',17('-'),'+',12X))
  103 FORMAT('0',3(':  ',I3,'  :',2(F5.0,1X),F5.0,':',12X))
  104 FORMAT('0',3('+',7('-'),'+',17('-'),'+',12X))
      END
```

2. Equations for mined areas

The models for mined areas are partially interactive and partially additive.

a. Forage production model

(1) Interactive component equation (Equation 3)

$$\widehat{\text{Production}} = 0.0061896 * \text{YPPR} * \text{YPGS} * (\text{PR})^{1.6} * \begin{cases} 1.04368 \text{ (native)} \\ 1.17448 \text{ (introduced)} \end{cases} \quad \text{Kind of vegetation}$$

$$\text{YPPR} = e^{-\left|\frac{\frac{\text{AGE}}{7} - 1}{0.9}\right|^{4.6}}$$

If GS ≤ 85

$$\text{YPGS} = 940 + 2510 * e^{-\left|\frac{\frac{\text{GS}}{85} - 1}{0.16}\right|^{4}}$$

If GS > 85

$$\text{YPGS} = 2250 + 1200 * e^{-\left|\frac{\frac{\text{GS}}{85} - 1}{0.12}\right|^{4}}$$

LIMITS

$5 \leq \text{PR} \leq 25$ PR = annual precipitation, inches
$50 \leq \text{GS} \leq 180$ GS = growing season, days
$0 \leq \text{AGE} \leq 7$ AGE = age of planting, years

(2) Additive component table (Table 1)

Component	Additive forage production (lbs/acre) Native	Introduced
Soil potassium (K)	[1]+ 5.4	[1]+ 4.1
Soil sodium (Na)	[1]– 0.088	[1]– 1.4
Soil pH	[2]+ 117.9	[2]+ 143.4
Tillage (Til)	+ 13.0	– 308.0
Seeding method (SM)		
broadcast	0	0
drilled	+ 341.0	– 783.0
Topsoil (TPS)	– 83.0	+ 99.0
Fertilizer (FER)	+ 369.0	+ 430.0
Irrigation (IRR)	+ 35.0	+ 418.0
Mulching (MUL)	– 178.0	+ 160.0
Seeding time (ST)		
spring	0	0
fall	+ 335.0	– 78.0
Intercept	[3]– 2216.0	[3]– 1181.0

[1]Multiply these production values by parts per million of soil component (potassium or sodium).

[2]Multiply these production values by pH units of soil acidity.

[3]These intercept values **must** be added to the total value of forage production.

LIMITS

$0 \leq \text{K} \leq 450$
$0 \leq \text{Na} \leq 1000$
$4 \leq \text{pH} \leq 9$

(3) FORTRAN IV computer programs for estimating forage production (equation 3) for:

(a) Native vegetation

```
      DIMENSION IX(5,3),LB(3),A(7) ,XT(3)
      INTEGER*2 N(7)
      DATA IX/5,50,0,0,4,15,85,200,150,6,25,120,400,300,8/,
     *N/7*0/,X/'X'/,A/7*' '/,B/' '/
      CALL ERRSET (208,256,-1,0)
      DO 45 MM=1,3
      DO 45 M=1,3
      DO 45 L=1,3
      DO 45 K=1,3
      DO 20 I=1,3
      Z=IX(2,K)
      YPPR=(EXP(-(ABS((5.0/7.0-1.0)/.9)**4.6)))
      IF(IX(2,K).GT.85) GO TO 10
      YPG1=2510*(EXP(-(ABS((Z/85.-1.)/.16)**4)))+940
      XT(I)=YPPR*YPG1*.00618959*FLOAT(IX(1,I))**1.6
      GO TO 15
   10 YPG2=1200*(EXP(-(ABS((Z/85.-1.)/.12)**4)))+2250
      XT(I)=YPPR*YPG2*.00618959*FLOAT(IX(1,I))**1.6
   15 XT(I)=XT(I)*1.04368
C *** FOR ZERO COMPUTATION. ***
      LB(I)=-2215.925+XT(I)+IX(3,L)*5.39904+IX(4,M)*(-.08788242)+
     *IX(5,MM)*117.9473
      IF(LB(I).LT.0) LB(I)=0
   20 CONTINUE
      PRINT 99
      PRINT 100,(IX(1,I),IX(2,K),IX(3,L),IX(4,M),IX(5,MM),I=1,3)
      PRINT 101,(LB(I),I=1,3)
      DO 40 I=1,127
      READ(9,102,END=50) N
      DO 25 J=1,3
      LB(J)=-2215.925+XT(J)+IX(3,L)*5.39904+IX(4,M)*(-.08788242)+
     *IX(5,MM)*117.9473+N(1)*13.30125+N(2)*340.7638+N(3)*(-83.07744)+
     *N(4)*368.7023+N(5)*34.89601+N(6)*(-177.5357)+N(7)*334.5793
      IF(LB(J).LT.0) LB(J)=0
   25 CONTINUE
      DO 30 J=1,7
      IF(N(J).EQ.1) A(J)=X
   30 CONTINUE
      PRINT 103,(A,LB(J),J=1,3)
      DO 35 J=1,7
      IF(A(J).EQ.X) A(J)=B
   35 CONTINUE
   40 CONTINUE
      REWIND 9
   45 CONTINUE
   50 STOP
   99 FORMAT('1',52X,'M I N E D   A R E A S'/' ',41X,
     *'N A T I V E   S P E C I E S   P R O D U C T I O N')
  100 FORMAT('0',3(35('-'),9X)/' ',3(': PR   GS   K',
     *'    NA   PH    :      :',9X)/' ',3(': ',I2,2X,4(I3,2X),
     *2X,':      :',9X)/' ',3(':',27X,': PROD:',9X)/' ',
     *3(':',7('---+'),'  PER:',9X)/' ',3(':TIL  SM TPS ',
     *'FER IRR MUL  ST: ACRE:',9X)/' ',3(8('+---'),'--+',
     *9X))
  101 FORMAT(' ',3(':',27X,I6,':',9X))
  102 FORMAT(7I1)
  103 FORMAT(' ',3(':',1X,A1,6(3X,A1),1X,I6,':',9X))
      END
```

(b) Introduced vegetation

```
      DIMENSIØN IX(5,3),LB(3),A(7) ,XT(3)
      INTEGER*2 N(7)
      DATA IX/5,50,0,0,4,15,85,200,150,6,25,120,400,300,8/,
     *N/7*0/,X/'X'/,A/7*' '/,B/' '/
      CALL ERRSET (208,256,-1,0)
      DØ 45 MM=1,3
      DØ 45 M=1,3
      DØ 45 L=1,3
      DØ 45 K=1,3
      DØ 20 I=1,3
      Z=IX(2,K)
      YPPR=(EXP(-(ABS((5.0/7.0-1.0)/.9)**4.6)))
      IF(IX(2,K).GT.85) GØ TØ 10
      YPG1=2510*(EXP(-(ABS((Z/85.-1.)/.16)**4)))+940
      XT(I)=YPPR*YPG1*.00618959*FLØAT(IX(1,I))**1.6
      GØ TØ 15
   10 YPG2=1200*(EXP(-(ABS((Z/85.-1.)/.12)**4)))+2250
      XT(I)=YPPR*YPG2*.00618959*FLØAT(IX(1,I))**1.6
   15 XT(I)=XT(I)*1.17448
C *** FØR ZERØ CØMPUTATIØN. ***
      LB(I)=-1180.820+XT(I)+IX(3,L)*4.08251+IX(4,M)*(-1.361515)+
     *IX(5,MM)*143.3554
      IF(LB(I).LT.0) LB(I)=0
   20 CØNTINUE
      PRINT 99
      PRINT 100,(IX(1,I),IX(2,K),IX(3,L),IX(4,M),IX(5,MM),I=1,3)
      PRINT 101,(LB(I),I=1,3)
      DØ 40 I=1,127
      READ(9,102,END=50) N
      DØ 25 J=1,3
      LB(J)=-1180.820+XT(J)+IX(3,L)*4.08251+IX(4,M)*(-1.361515)+
     *IX(5,MM)*143.3554+N(1)*(-307.9574)+N(2)*(-782.8676)+N(3)*99.46091+
     *N(4)*429.5873+N(5)*418.1331+N(6)*159.9511+N(7)*(-78.4929)
      IF(LB(J).LT.0) LB(J)=0
   25 CØNTINUE
      DØ 30 J=1,7
      IF(N(J).EQ.1) A(J)=X
   30 CØNTINUE
      PRINT 103,(A,LB(J),J=1,3)
      DØ 35 J=1,7
      IF(A(J).EQ.X) A(J)=B
   35 CØNTINUE
   40 CØNTINUE
      REWIND 9
   45 CØNTINUE
   50 STØP
C     DEBUG INIT(LB,XT),UNIT(2)
   99 FØRMAT('1',52X,'M I N E D   A R E A S'/' ',33X,
     *'I N T R Ø D U C E D   S P E C I E S   P R Ø D U C T I Ø N')
  100 FØRMAT('0',3(35('-'),9X)/' ',3(': PR   GS   K',
     *'   NA   PH    :      :',9X)/' ',3(': ',I2,2X,4(I3,2X),
     *2X,':      :',9X)/' ',3(':',27X,': PRØD:',9X)/' ',
     *3(':',7('---+'),'  PER:',9X)/' ',3(':TIL  SM TPS ',
     *'FER IRR MUL  ST: ACRE:',9X)/' ',3(8('+---'),'--+',
     *9X))
  101 FØRMAT(' ',3(':',27X,I6,':',9X))
  102 FØRMAT(7I1)
  103 FØRMAT(' ',3(':',1X,A1,6(3X,A1),1X,I6,':',9X))
      END
```

b. Plant cover density model

(1) Interactive component equation (Equation 4)

$$\text{Cover} = YP * \left[\frac{e^{-\left|\frac{\frac{PR}{26} - 1}{1 - I}\right|^{N}} - e^{-\left\{\frac{1}{1 - I}\right\}^{N}}}{1 - e^{-\left\{\frac{1}{1 - I}\right\}^{N}}} \right] * \begin{array}{ll} & \text{Kind of } \underline{\text{vegetation}} \\ 1.07686 & \text{(Native)} \\ 0.98256 & \text{(introduced)} \end{array}$$

Where

$$N = 1 + NYP * \left(1.1397 * e^{-\left|\frac{\frac{AGE}{10} - 1}{0.88}\right|^{5.8}} - 0.1397\right)$$

$$NYP = 1.8 + e^{-\left|\frac{\frac{(180 - GS)}{108} - 1}{0.52}\right|^{15}}$$

$$I = 0.38 + (IYP/10) * AGE$$

$$IYP = 0.29 * e^{-\left|\frac{\frac{GS}{180} - 1}{0.5105}\right|^{12}} - 0.2$$

$$YP = YPGS * \left[\frac{e^{-\left|\frac{\frac{(AGE + 1)}{11} - 1}{(1 - IGS)}\right|^{10}} - e^{-\left\{\frac{1}{(1 - IGS)}\right\}^{10}}}{1 - e^{-\left\{\frac{1}{(1 - IGS)}\right\}^{10}}} \right]$$

$$YPGS = 100 * e^{-\left|\frac{\frac{GS}{180} - 1}{0.78}\right|^{8}}$$

$$IGS = 0.1 + 0.23 * e^{-\left|\frac{\frac{(180 - GS)}{180} - 1}{0.36}\right|^{6.5}}$$

LIMITS

$5 \leq PR \leq 25$	PR = annual precipitation, inches
$50 \leq GS \leq 180$	GS = growing season, days
$0 \leq AGE \leq 7$	AGE = age of planting, years

(2) Additive component table (Table 2)

Component	Additive plant cover density (percent) Native	Introduced
Soil potassium (K)	[1]0.0892	[1]0.0205
Soil sodium (Na)	[1]− 0.0186	[1]0.0093
Soil pH	[2]− 4.2	[2]+ 7.6
Tilliage (Til)	− 3.9	− 10.0
Seeding method (SM)		
broadcast	0	0
drilled	− 1.8	+ 1.0
Topsoil (TPS)	+ 6.0	+ 0.4
Fertilizer (FER)	+ 11.2	+ 30.9
Irrigation (IRR)	+ 0.6	+ 15.0
Mulching (MUL)	+ 15.2	+ 4.8
Seeding time (ST)		
spring	0	0
fall	− 5.6	+ 19.0
Intercept	[3]+ 12.9	[3]− 74.3

[1]Multiply these density (percent) values by parts per million of soil component (potassium or sodium).
[2]Multiply these density values by pH units of soil acidity.
[3]These intercept values **must** be added to the total value of cover density.

LIMITS

$0 \leq K \leq 450$
$0 \leq Na \leq 1000$
$4 \leq pH \leq 9$

(3) FORTRAN IV computer programs for estimating plant cover density (equation 4) for:
(a) Native vegetation

```
      DIMENSION IX(5,3),LB(3),A(7) ,XT(3)
      INTEGER*2 N(7)
      DATA IX/5,50,0,0,4,15,85,200,150,6,25,120,400,300,8/,
     *N/7*0/,X/'X'/,A/7*' '/,B/' '/
      CALL ERRSET (208,256,-1,0)
      DO 45 MM=1,3
      DO 45 M=1,3
      DO 45 L=1,3
      DO 45 K=1,3
      DO 20 I=1,3
      V=IX(1,I)
      Z=IX(2,K)
      AYP=1.8+EXP(-(ABS(((180-Z)/180.-1.)/.52)**15))
      BYP=.29*(EXP(-(ABS((Z/180.-1.)/.5105)**12)))-.2
      YPGS=100.*(EXP(-(ABS((Z/180.-1.)/.78)**8)))
      BGS=.23*(EXP(-(ABS(((180.-Z)/180.-1.)/.36)**6.5)))+.1
      AX=AYP*(1.1397*(EXP(-(ABS((5./10.-1.)/.88)**5.8)))-.1397)+1
      BX=(BYP/10.)*5.+.38
      CN=EXP(-(ABS(((5.+1)/11.-1.)/(1.-BGS))**10))
      RN=EXP(-((1./(1.-BGS))**10))
      YP=((CN-RN)/(1.-RN))*YPGS
      TN=EXP(-(ABS((V/26.-1.)/(1.-BX))**AX))
      UN=EXP(-((1./(1.-BX))**AX))
      COV=((TN-UN)/(1.-UN))*YP
      XT(I)=COV*1.07686
C *** FOR ZERO COMPUTATION. ***
      LB(I)=12.86572+XT(I)+IX(3,L)*.08918672+IX(4,M)*(-.01861335)+
     *IX(5,MM)*(-4.176856)
      IF(LB(I).LT.0) LB(I)=0
      IF(LB(I).GT.100) LB(I)=100
   20 CONTINUE
      PRINT 99
      PRINT 100,(IX(1,I),IX(2,K),IX(3,L),IX(4,M),IX(5,MM),I=1,3)
      PRINT 101,(LB(I),I=1,3)
      DO 40 I=1,127
      READ(9,102,END=50) N
      DO 25 J=1,3
      LB(J)=12.86572+XT(J)+IX(3,L)*.08918672+IX(4,M)*(-.01861335)+
     *IX(5,MM)*(-4.176856)+N(1)*(-3.929149)+N(2)*(-1.835147)+N(3)*
     *6.056078+N(4)*11.19705+N(5)*.5945488+N(6)*15.16765+N(7)*
     *(-5.601713)
      IF(LB(J).LT.0) LB(J)=0
      IF(LB(J).GT.100) LB(J)=100
   25 CONTINUE
      DO 30 J=1,7
      IF(N(J).EQ.1) A(J)=X
   30 CONTINUE
      PRINT 103,(A,LB(J),J=1,3)
      DO 35 J=1,7
      IF(A(J).EQ.X) A(J)=B
   35 CONTINUE
   40 CONTINUE
      REWIND 9
   45 CONTINUE
   50 STOP
C     DEBUG INIT(LB,XT),UNIT(2)
   99 FORMAT('1',52X,'M I N E D   A R E A S'/' ',41X,
     *'N A T I V E   S P E C I E S   C O V E R')
  100 FORMAT('0',3(35('-'),9X)/' ',3(': PR    GS    K',
     *'    NA   PH    :        :',9X)/' ',3(': ',I2,2X,4(I3,2X),
     *2X,':       :',9X)/' ',3(':',27X,':       :',9X)/' ',
     *3(':',7('---+'),'  %  :',9X)/' ',3(':TIL  SM TPS ',
     *'FER IRR MUL  ST:COVER:',9X)/' ',3(8('+---'),'--+',
     *9X))
  101 FORMAT(' ',3(':',27X,I6,':',9X))
  102 FORMAT(7I1)
  103 FORMAT(' ',3(':',1X,A1,6(3X,A1),1X,I6,':',9X))
      END
```

(b) Introduced vegetation

```
      DIMENSION IX(5,3),LB(3),A(7) ,XT(3)
      INTEGER*2 N(7)
      DATA IX/5,50,0,0,4,15,85,200,150,6,25,120,400,300,8/,
     *N/7*0/,X/'X'/,A/7*' '/,B/' '/
      CALL ERRSET (208,256,-1,0)
      DO 45 MM=1,3
      DO 45 M=1,3
      DO 45 L=1,3
      DO 45 K=1,3
      DO 20 I=1,3
      V=IX(1,I)
      Z=IX(2,K)
      AYP=1.8+EXP(-(ABS(((180-Z)/180.-1.)/.52)**15))
      BYP=.29*(EXP(-(ABS((Z/180.-1.)/.5105)**12)))-.2
      YPGS=100.*(EXP(-(ABS((Z/180.-1.)/.78)**8)))
      BGS=.23*(EXP(-(ABS(((180.-Z)/180.-1.)/.36)**6.5)))+.1
      AX=AYP*(1.1397*(EXP(-(ABS((5./10.-1.)/.88)**5.8)))-.1397)+1
      BX=(BYP/10.)*5.+.38
      CN=EXP(-(ABS(((5.+1)/11.-1.)/(1.-BGS))**10))
      RN=EXP(-((1./(1.-BGS))**10))
      YP=((CN-RN)/(1.-RN))*YPGS
      TN=EXP(-(ABS((V/26.-1.)/(1.-BX))**AX))
      UN=EXP(-((1./(1.-BX))**AX))
      COV=((TN-UN)/(1.-UN))*YP
      XT(I)=COV*.98256
C *** FOR ZERO COMPUTATION. ***
      LB(I)=-74.25282+XT(I)+IX(3,L)*.02049003+IX(4,M)*.009275586+
     *IX(5,MM)*7.643977
      IF(LB(I).LT.0) LB(I)=0
      IF(LB(I).GT.100) LB(I)=100
   20 CONTINUE
      PRINT 99
      PRINT 100,(IX(1,I),IX(2,K),IX(3,L),IX(4,M),IX(5,MM),I=1,3)
      PRINT 101,(LB(I),I=1,3)
      DO 40 I=1,127
      READ(9,102,END=50) N
      DO 25 J=1,3
      LB(J)=-74.25282+XT(J)+IX(3,L)*.02049003+IX(4,M)*.009275586+
     *IX(5,MM)*7.643977+N(1)*(-10.02594)+N(2)*1.02198+N(3)*
     *.3622047+N(4)*30.88224+N(5)*15.06255+N(6)*4.778853+N(7)*18.96781
      IF(LB(J).LT.0) LB(J)=0
      IF(LB(J).GT.100) LB(J)=100
   25 CONTINUE
      DO 30 J=1,7
      IF(N(J).EQ.1) A(J)=X
   30 CONTINUE
      PRINT 103,(A,LB(J),J=1,3)
      DO 35 J=1,7
      IF(A(J).EQ.X) A(J)=B
   35 CONTINUE
   40 CONTINUE
      REWIND 9
   45 CONTINUE
   50 STOP
   99 FORMAT('1',52X,'M I N E D   A R E A S'/' ',33X,
     *'I N T R O D U C E D   S P E C I E S   C O V E R')
  100 FORMAT('0',3(35('-'),9X)/' ',3(': PR   GS   K',
     *'    NA   PH     :      :',9X)/' ',3(': ',I2,2X,4(I3,2X),
     *2X,':      :',9X)/' ',3(':',27X,':      :',9X)/' ',
     *3(':',7('---+'),'  %  :',9X)/' ',3(':TIL  SM TPS ',
     *'FER IRR MUL  ST:COVER:',9X)/' ',3(8('+---'),'--+',
     *9X))
  101 FORMAT(' ',3(':',27X,I6,':',9X))
  102 FORMAT(7I1)
  103 FORMAT(' ',3(':',1X,A1,6(3X,A1),1X,I6,':',9X))
      END
```

3. Statistics pertinent to each model (Table 3)

Prediction model	Number of transects (n)	Coefficient of determination (R^2)	Standard error of estimate ($S_{y \cdot x}$)
	Statistics		
Forage production weight on unmined areas	83	0.545	356 lbs/acre
Plant cover density on unmined areas	83	0.785	13.1 percent
Forage production weight on mined and revegetated areas			
Native vegetation	44	0.685	380 lbs/acre
Introduced vegetation	33	0.735	547 lbs/acre
Plant cover density on mined and revegetated areas			
Native vegetation	44	0.666	17.5 percent
Introduced vegetation	33	0.615	19.2 percent

Packer, Paul E., Chester E. Jensen, Edward L. Noble, and John A. Marshall. 1982. Models to estimate revegetation potentials of land surface mined for coal in the West. USDA For. Serv. Gen. Tech. Rep. INT-123, 25 p. Intermt. For. and Range Exp. Stn., Ogden, Utah 84401.

Practical criteria for measuring success of revegetation of land surface mined for coal in the West, namely, the amount of forage produced and the density of plant cover developed, are affected significantly by at least two major climatic factors that are not readily susceptible to alteration (precipitation and growing season length); by three properties of spoil materials that are subject to limited modification through management (potassium, sodium, and pH). Revegetation success is also influenced by seven revegetation treatments, each of which provides at least two management alternatives, and by the age of the vegetation. These characteristics account for from one-half to three-fourths of the total variance in forage production and plant cover density on these revegetated lands.

KEYWORDS: strip mining, surface mining, reclamation, revegetation, production potentials, cover potentials

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General Technical
Report INT-124

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How to Interpret Tree Mortality on Large-Scale Color Aerial Photographs

Frank C. Croft
Robert C. Heller
David A. Hamilton, Jr.

AUTHORS

FRANK C. CROFT is an image analyst with Technicolor Graphic Services at NASA Ames Research Center, Moffett Field, Calif. He has been analyzing digital Landstat imagery of Arizona and Nevada using a variety of hardware and software systems since 1980. Before that, he was a graduate research assistant working on a doctoral program at Colorado State University in forestry and remote sensing. He received a B.S. and an M.S. in forest resources from the University of Idaho in 1976 and 1978, respectively. Prior to that he was a pilot in the Air Force for 6 years after graduating from the United States Air Force Academy with a B.S. in 1969.

ROBERT C. HELLER, research professor of remote sensing at the College of Forestry, Wildlife and Range Sciences, has been teaching and conducting research since 1974 at the University of Idaho, Moscow. Prior to that time he was work unit leader of the nationwide Remote Sensing Project located at the Pacific Southwest Forest and Range Experiment Station, Berkeley, Calif. He received a B.S. in botany and an M.F. in forest management from Duke University in 1940 and 1941, respectively.

DAVID A. HAMILTON, JR., is a research forester working in timber measurements and management planning research at the Forestry Sciences Laboratory, Moscow, Idaho. Since receiving his Ph.D. in forestry from Iowa State University in 1970, he has worked on the sampling and modeling of forest mortality and on the problem of specifying optimal precision levels for resource inventories.

RESEARCH SUMMARY

Related work has shown large-scale 70 mm color aeria photography to be an efficient means of measuring annual mortality. Equipment needed to interpret the photographs include a light table, a 2- or 4-power stereoscope (or combination 2- and 4-power), a micrometer wedge, and a template to define a subplot on which green trees are to be measured.

Three types of information are interpreted from the photographs. All trees that have died in the past year are identified by species. A subset of the green trees are counted by species. Crown diameters are measured on all trees that have died in the past year and on the subse of green trees.

Time needed to interpret a one-third-mile (0.54 km) stri of photography (eight frames at a scale of 1:2400) depends on the density and relative size of trees to be measured. Thus, although the average time required to measure a strip is approximately 1 hour, there is considerable variability in time needed to interpret photo strips located systematically over the forest.

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INTRODUCTION

This paper describes photo interpretation techniques used in sampling for mortality rates with large-scale aerial photographs in the Inland Empire. It is assumed that the interpreter has the ability to see in stereo and has a basic working knowledge of aerial photo interpretation. The more familiar the interpreter is with the area being measured, the easier and more accurate the interpretation will be.

In the USDA Forest Service's Northern Region, current management planning inventory methods rely on ground point sampling methods. These methods provide efficient estimates of stand development using variables such as volume, diameter, diameter growth rate, and height of trees in the plot. However, they do not provide an efficient method for collecting information on tree mortality rates. This is true because (1) expected mortality rates are low, about 0.5 percent per year (that is, one tree out of every 200 will die in a year's time); (2) mortality is not distributed uniformly over the entire forest, but is usually clustered; and (3) mortality is not distributed uniformly through time. To obtain acceptable precision in estimates of mortality rate with the current Northern Region sampling design, sample size would have to be greatly increased.

Another problem with existing techniques is that mortality trees are defined as trees the field crews estimate have died in the past 5 years. This is a task even trained entomologists and pathologists find extremely difficult to accurately and efficiently perform.

Because of the deficiencies of ground estimation of tree mortality, a new, relatively inexpensive method employing the use of large-scale color transparencies (70 mm format) was developed by Hamilton (1980[1]). With this method the interpreter has only to estimate mortality for the previous year. Flight strips one-third mile (0.54 km) long (eight frames at a scale of 1:2400) are systematically selected at the center of each township. The photography is flown between mid-July and mid-September. Interpretation of the imagery can then be delayed until the completion of the field season. In addition to its use for sampling mortality, the imagery also gives the manager a high resolution visual record of those parts of the forest included in the sample.

ACQUISITION OF 70MM COLOR PHOTOGRAPHY

Good interpretation results are dependent on two things: the skill of the interpreter and the quality of the photographs. Methods of improving the skill of the interpreter will be discussed later. Quality control of aerial photography is accomplished by contract specifications that should be clearly outlined before the flight to protect

[1] Hamilton, David A., Jr. 1980. Sampling and estimation of mortality using large scale aerial photography. Review draft. Manuscript on file at Intermountain Station's Forestry Sciences Laboratory, Moscow, Idaho, 26 p.

both parties. After the photography is flown, the color transparencies should be inspected for compliance. Among the specifications listed below, the first five may be considered standard for the majority of aerial photographic contracts. The last six are applicable to aerial photography acquired primarily for this type of mortality sampling.

Specifications:

1. Drift - less than 15 percent of photo width
2. Crab - less than 4 degrees
3. Image motion - less than 0.002 inches (0.05 mm)
4. Endlap - 60 percent ± 5 percent
5. Tilt - less than 3 degrees from vertical
6. Camera - 70 mm format with long focal length lens (135 mm - 304 mm)
7. Film - Kodak Ektachrome MS2448 (normal color transparencies)
8. Filter - haze filter (some combination of HF2, 3, 4, 5)
9. Scale - 1:1600-1:2400 preferred for identification of tree species (Heller and others 1977; Hamilton 1981)
10. Exposure - tree crown neither washed out from overexposure, nor shadows and colors too dark from underexposure. Photos should be taken from 1000 to 1430 local sun time to assure maximum sun angle and minimum shadow effect. Photos taken under a high overcast are also acceptable because they produce shadowless images that improve interpretation of tree species.
11. Photo number - nine photos per strip numbered consecutively would be ideal; this study included only eight photos per strip. Film takeup direction should be the same as flight direction. This will provide a sequence of photos that the interpreter may view in stereo and that will match small-scale resource photos or maps.

EQUIPMENT NEEDED FOR INTERPRETATION

Proper equipment (fig. 1) can aid the interpreter in the job. The viewing table should use cool-white fluorescent tubes or some other balanced light source. The 70 mm format permits each frame to be viewed stereoscopically in roll form with a pocket stereoscope. The distance between frames is roughly equivalent to most interpreters' interpupillary distance. For this study, an Abrams 2/4-power, model CB-1 stereoscope was used. The selective lenses with 2-power or 4-power magnification were a considerable asset in identifying tree species.

Figure 1.--A light table, Abrams 2/4-power stereoscope (in the 4-power position), square grid overlay (not clearly visible on frame under stereoscope), and micrometer wedge were used to interpret the 70 mm photo strips. The tally sheet was readily available for annotating data. The medium-scale resource photography is used to gain an understanding of the surrounding area.

A square grid overlay—each grid line 0.2 inch (5 mm) apart—is placed over each frame to be interpreted to insure the complete frame is examined (fig. 2). The entire overlay should be just larger than a single 70 mm frame. A square subplot, 0.6 inch (15 mm) on a side, is established in the center of the grid overlay.

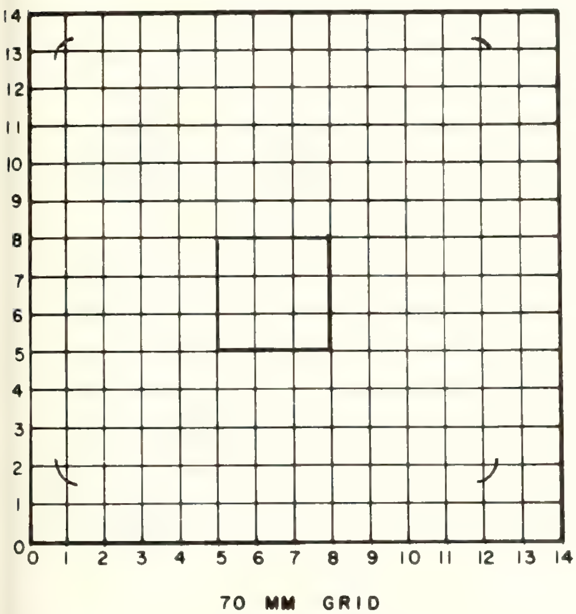

Figure 2.--A square grid overlay was used to outline the subplot of nine squares. Reference marks near the outside of the grid insure exact alinement on each frame.

The last piece of interpretation equipment is a micrometer wedge, which is used to measure crown widths. Because of the size of the trees in the Inland Empire and the scale of the photography, two wedges are needed, 0.001 to 0.150 inch and 0.150 to 0.300 inch (0.025 to 3.81 mm and 3.81 to 7.62 mm) (fig 3.). The wedge was chosen over other types of crown width measuring instruments because of its simplicity and its ease of use on 70 mm format transparencies.

PHOTO INTERPRETATION PROCEDURES

Stand height cover classes[2] are initially delineated on medium-scale resource photography. Then this classification is transferred from medium-scale resource photography to the 70 mm mortality photography.

Every third frame of each photo strip is interpreted. On this set of photography we interpreted the second, fifth, and eighth frames. Since the pictures have 60 percent overlap, this results in little duplication of coverage on interpreted frames. As a part of this study, the beginning and ending times of interpretation for each frame were recorded.

The color transparencies were oriented on the light table so that the shadows face toward the interpreter, who advances the first frame to be interpreted to the middle of the light table and sets the stereoscope over the transparencies. At this time, any ground data available and any previous photos of the area should be examined. The site should be viewed stereoscopically to determine gross characteristics (that is, slope, aspect, elevation, habitat type, and so forth). The grid should be placed over each frame to be interpreted so that the subplot is established in a consistent location close to the center of the frame.

[2] In the Northern Region, forest stands are separated into 26 aerial photo classes. These are collapsed into nine classes for mortality sampling and estimation. A description of the nine classes is contained in appendix A.

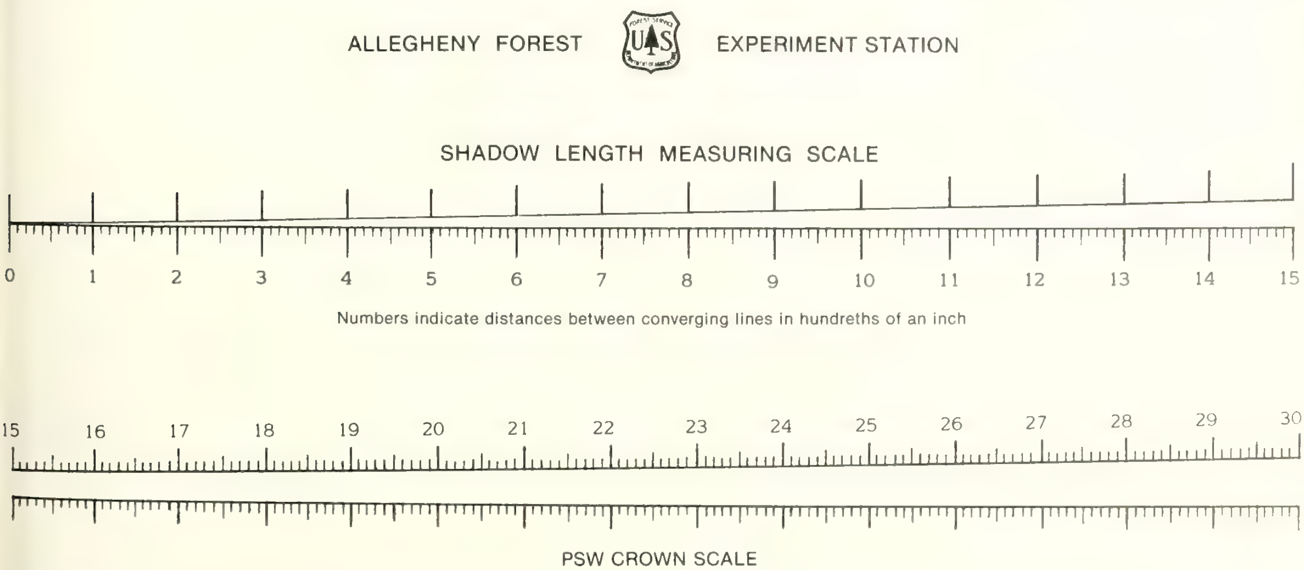

Figure 3.--A micrometer wedge was used to measure crown diameters. The first piece (top) measures distances from 0.001 to 0.150 inch (0.025 to 3.81 mm) while the second (bottom) measures from 0.150 to 0.300 inch (3.81 to 7.62 mm).

The interpreter may now begin to interpret the photos by locating all trees that have died in the past year. Such a tree is one on which the majority of the needles are retained and the foliage is brightly discolored. Trees dead for more than a year will usually have a dull discoloration of the foliage, and a significant portion of the needles will be gone. Interpretation of photographs flown over the same plots on two successive years has demonstrated that these criteria correctly categorize 90 percent of the 1-year mortality trees. Dying trees, identified by their slightly offgreen crown, are not counted as 1-year mortality trees. These trees will meet the definition of 1-year mortality trees in the following year. To include them in the count of mortality trees would result in double counting and inflated estimates of mortality rates.

The interpreter, who begins in one square and systematically covers all squares, should identify dead trees by species, measure their crown width with the micrometer wedge while viewing in stereo, and record whether each dead tree is located in or out of the central subplot. These data should be recorded on a tally sheet similar to the one in figure 4. If a dead tree is located outside the central subplot, its location is coded as 1. Location of all other measured trees (green and dead) is coded as 0.

Photo plot number	PI code	Species	Status (dead or alive)	Crown width	Size of subplot	Tree location
51-2	1	DF	D	.090	0	1
		PP	D	.084	0	1
		DF	D	.076	0	1
		PP	D	.063	0	1
		DF	D	.085	0	1
		DF	A	.139	0	0
		DF	A	.066	0	0
		DF	A	.149	0	0
51-5	1	WP	D	.098	0	0
		WP	D	.072	0	0
		WP	D	.096	0	0
		DF	D	.062	0	1
		WP	D	.078	0	1
		GF	D	.069	0	1
		WP	A	.105	0	0
		WP	A	.078	0	0
		DF	A	.125	0	0
51-8	1	WP	D	.079	1	1
		DF	D	.075	1	1
		GF	D	.091	1	1
		GF	D	.096	1	1
		DF	D	.086	1	1
		GF	A	.090	1	0
		DF	A	.136	1	0
		DF	A	.106	1	0
		WP	A	.069	1	0
		.	.	.	.	.
		.	.	.	.	.
		.	.	.	.	.

Figure 4.—Example of data recorded on tally sheet.

Technically, the only valid ways to measure crown diameter are at right angles to the radial displacement or in a real stereo image. However, because a relatively long focal length lens (12 inches or 304 mm) is usually used for this scale photography, and the majority of the trees measured are near the principal point of the frame of 70 mm photography, the errors in measurement due to radial distortion of the crown should be very small. The purpose of measuring crown diameter is to obtain a relative measure of size that may be used to rank the tree in the cumulative crown area distribution. Thus, there is little justification to expend the additional effort required to more accurately measure crown diameter.

Green trees are only measured within the central subplot. Generally, all trees within these central nine squares are to be identified by species and have their crown width measured. However, when the stand is very dense and homogeneous, a subsample of the central subplot may be selected for measuring green trees. The subsample is defined as the four squares in a randomly selected corner of the central subplot. The subsample is most easily selected by numbering the four corners of the central subplot and then selecting a number from a prepared list of uniform random numbers in the range of one to four.

If only four squares are measured as the green tree subplot, size of subplot is recorded as 1 for all trees (green and dead) measured on that frame. If nine squares are measured as the green tree subplot, size of subplot is coded as 0 for all measured trees. This further subsampling avoids excessive, time-consuming measurement of similar trees and does not introduce bias into the sample.

SPECIES IDENTIFICATION

Sayn-Wittgenstein (1978) developed a recognition manual for Canadian tree species that includes drawings and photographs for identifying trees on both large- and medium-scale aerial photography. Heller and others (1964), working in the northeast United States, developed general descriptions (appendixes B and C) of a few characteristics that might help identify trees in other parts of the United States. The characteristics listed in the appendixes (crown apices, crown margins, and foliage characteristics) and crown color have proven to be major distinguishing factors in species identification for species encountered in the Northern Region. Since all four characteristics change by site, season, and year, a standard description is difficult to develop. The impact on interpretation of this variation in the spectral signature of a single species is complicated by the variety of species in the Northern Region.

Six major trees in the Northern Region—ponderosa pine, western larch, Douglas-fir, grand fir, western white pine, and western redcedar—have been identified on large-scale aerial photography by Heller and others (1977). They found that pole and sapling size trees have similar crown shape and foliage characteristics regardless of species, and were therefore harder to identify than mature trees.

For this paper, three forestry students with backgrounds in aerial photo interpretation were used to identify mortality on 1:2400 color transparencies flown on the Clearwater and Kootenai National Forests in Idaho and on the National Forests straddling the continental divide in Montana. They determined that the following trees, when mature, could be identified by species: ponderosa pine, western white pine, lodgepole pine, Douglas-fir, grand fir, subalpine fir, Englemann spruce, and western redcedar. Those trees that could only be identified by genus were hemlock, larch, and juniper. Two pines, white bark pine and limber pine, could not be separated and were considered as one. Difficulty was also encountered in separating hemlock from cedar. Surveying larch mortality presented a problem in that it was difficult to distinguish between dead trees and trees defoliated by larch casebearer. Further, larch is deciduous, making it difficult to date mortality on the basis of foliage retention.

Characteristics that could be used to identify mature trees by species with reasonable reliability were noted. Appendix D lists by tree species and major characteristics those distinguishing factors the three interpreters used to identify tree species.

As an additional photo interpretation aid, the stereograms in appendix E are included. Each stereogram contains identified trees. A drawing of the foliage characteristics (from appendix C) accompanies each identified tree. The photos demonstrate the variability in descriptive characteristics that exists in trees of the same species. The descriptions included in this paper should only be used as a starting point.

Each new photograph set will have a unique set of characteristics to be used in species identification and mortality dating. The most efficient means of determining this set of characteristics is to have the interpreters visit a small subset of the photo strips on the ground and compare their photo interpretation with what actually exists. This also serves as an excellent method of training interpreters.

ANALYSIS OF TIME OF INTERPRETATION

Time spent on the photo interpretation was analyzed. The data were recorded by forest and by the number of squares sampled within the subplot (four or nine). Results are shown in table 1.

Variation in areas sampled led to a wide range of interpretation times. The frame that took 1 minute had only two live ponderosa pine in the subplot and no dead trees. The frame that took 100 minutes contained a very dense dog-hair lodgepole pine stand. Generally, the lodgepole pine stands were the most dense and required the most time to measure because of the small crown size. However, lodgepole stands were easy to identify by species. Other factors that caused the interpretation time to increase were poor image quality and a large mix of different species in immature stands. The results of this analysis of time data indicate that an average of just under 1 hour is required to interpret each one-third-mile (0.54-km) strip of photography.

This paper only describes the interpretation techniques and the specifications for obtaining the photography. The sampling design used by the Northern Region and the estimation procedures used to estimate mortality are discussed by Hamilton (see footnote 1).

Table 1.—Time required to accomplish photo interpretation of 70 mm stereograms

Forest	Number of squares interpreted in subplot	Number of frames interpreted	Time in minutes		
			Range	Mean	Standard deviation
Clearwater	9	152	4-37	16.7	9.13
	4	7	18-45	27.6	9.18
	Combined	159	4-45	17.2	9.37
Kootenai	9	104	2-60	19.0	10.82
	4	52	10-73	24.1	11.23
	Combined	156	2-73	20.7	11.19
Montana	9	285	1- 50	16.3	7.53
	4	193	8-100	21.4	10.94
	Combined	478	1-100	18.6	9.81
Entire project	Combined	793	1-100	18.7	9.81

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1981. Large scale color aerial photography as a tool in sampling for mortality rates. USDA For. Serv. Res. Pap. INT-269, 8 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.

Heller, Robert C., G. E. Doverspike, and R. C. Aldrich.
1964. Identification of tree species on large scale panchromatic and color aerial photographs. USDA For. Serv. Agric. Handb. 261, 24 p., Washington, D.C.

Heller, Robert C., S. A. Sader, and W. A. Miller.
1977. Identification of preferred Douglas-fir tussock moth sites by photo interpretation of stand, site, and defoliation conditions. DFTM Final Report, Univ. Idaho, Moscow, 23 p. Coll. For., Wildl. and Range Sci.

Sayn-Wittgenstein, L.
1978. Recognition of tree species on aerial photographs. Inf. Rep. FMR-X-118, 97 p. For. Mange. Inst. Ottawa, Ont.

APPENDIX A

Aerial Photo Interpretation Classes for Mortality Sampling and Estimation

Photo interpretation class	Description
1	Stand height greater than 40 ft (12.2 m). Coarse texture, well or medium stocked. Cutover or uncut land.
2	Stand height greater than 40 ft (12.2 m). Fine texture, well or medium stocked. Cutover or uncut land.
3	Stand height greater than 40 ft (12.2 m). Coarse texture, poorly stocked. Cutover or uncut land.
4	Stand height greater than 40 ft (12.2 m). Fine texture, poorly stocked. Cutover or uncut land.
5	Stand height greater than 40 ft (12.2 m). Manageable or potentially manageable two-story stands. Understory well, medium, or poorly stocked. Cutover or uncut land.
6	Stand height less than 40 ft (12.2 m). Fine texture, well or medium stocked. Cutover, well and medium stocked residual after cutting.
7	Stand height less than 40 ft (12.2 m). Coarse texture, well, medium, or poorly stocked.
8	Stand height less than 40 ft (12.2 m). Fine texture, poorly stocked or apparently nonstocked. Cutover, poorly stocked residual or apparently nonstocked after cutting.
9	Other (noncommercial forest).

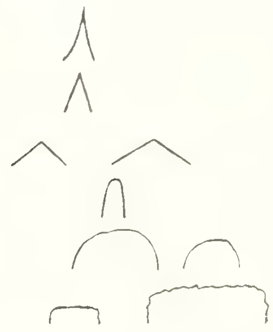
APPENDIX B

Interpretation Aid for Describing Tree Crowns[1]

Crown descriptions used by photo interpreters in species identification test

Crown apices

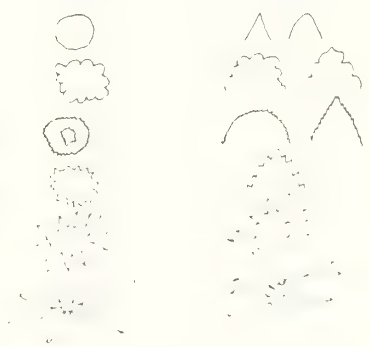
1. Acuminate
2. Acute
3. Obtuse
4. Narrowly rounded
5. Broadly rounded
6. Flat



Crown margins

Top view | Side view

1. Entire
2. Sinnuate
3. Finely serrate
4. Deeply serrate
5. Lobed
6. Parted



[1] Heller and others (1964).

APPENDIX C

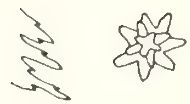
Interpretation Aid for Describing Foliage Characteristics[1]

Conifers

Code No.

1. Light tip to center of bole with fine texture

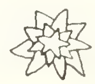
2. Layered branches



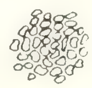
3. Wheel spokes

4. Columnar branches

5. Layered triangular-shaped branches



6. Small clumps



7. Small light spots in crown

8. Small starlike top

12. Dark spot in center of small clumps

16. Fine texture with scraggly long branches

---

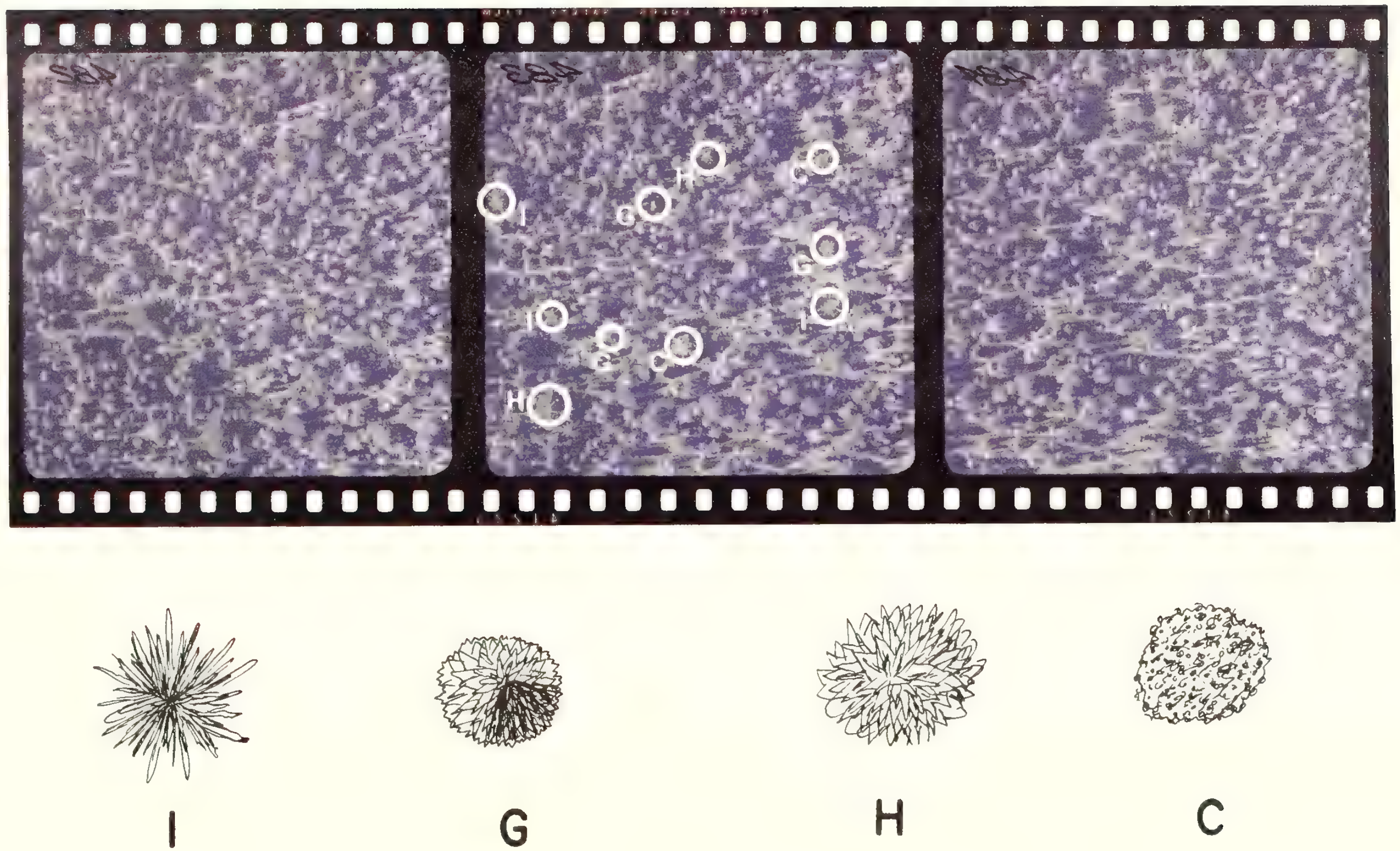
[1] Heller and others (1964).

APPENDIX D

Descriptions of Major Characteristics of Trees in the Northern Rocky Mountains[1]

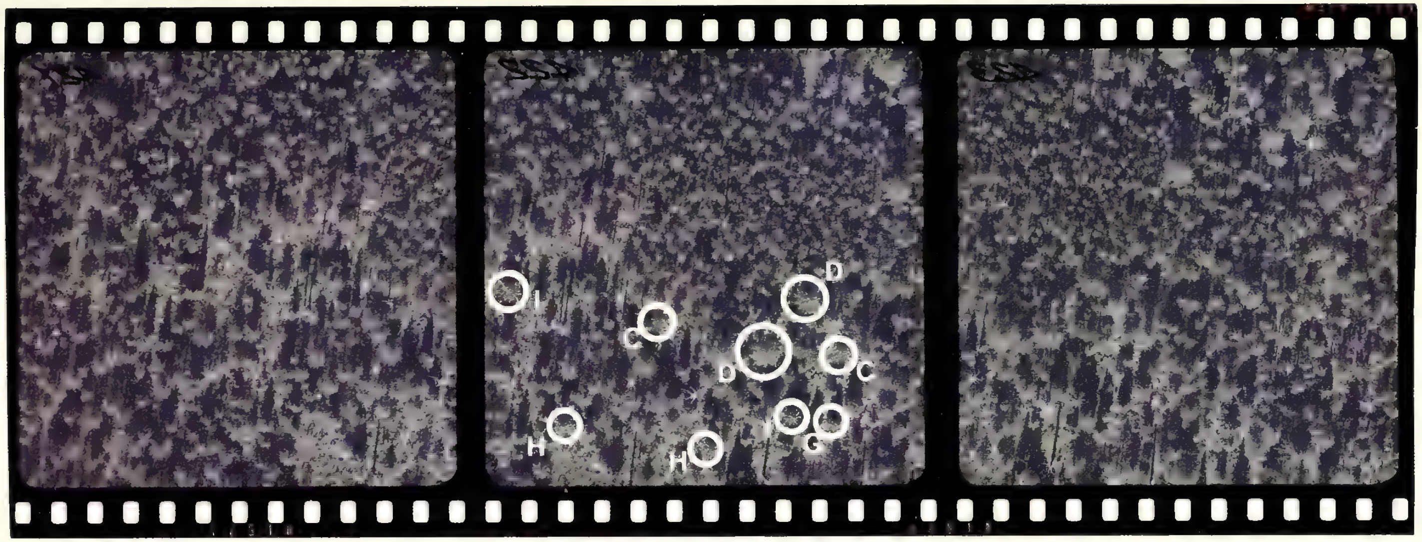
Species	Crown apex	Crown margin	Foliage characteristics	Color
A — ponderosa pine	broadly rounded	sinuate	dark spot in center of small clumps	yellow-green
B—western white pine	narrowly rounded	*lobed or serrate	small clumps	blue-green
C—lodgepole pine	acute to narrowly rounded	sinuate	very small clumps	yellow-green
D—larch	*acute to narrowly rounded	lobed	fine texture with long scraggly branches	light green
E—Douglas-fir	*acute	*deeply serated to lobed	layered, triangular shaped branches	medium green
F—grand fir	acute	*serrate to lobed	layered branches	dark green
G—subalpine fir	acuminate	*finely serrate	layered branches	dark green
H—Engelmann spruce	acute	serrate	layered branches, top may be a brownish-green due to presence of cones	*medium green
I—hemlock	acute	parted	wheel spokes	*dark green
J—western redcedar	acute	parted	wheel spokes	brownish yellow-green
K—white bark and limber pine	broadly rounded	*sinuate or lobed	scraggly branches	*blue-green to brownish green
L—juniper	broadly rounded	entire to sinuate	rounded and smooth	grey to light blue-green

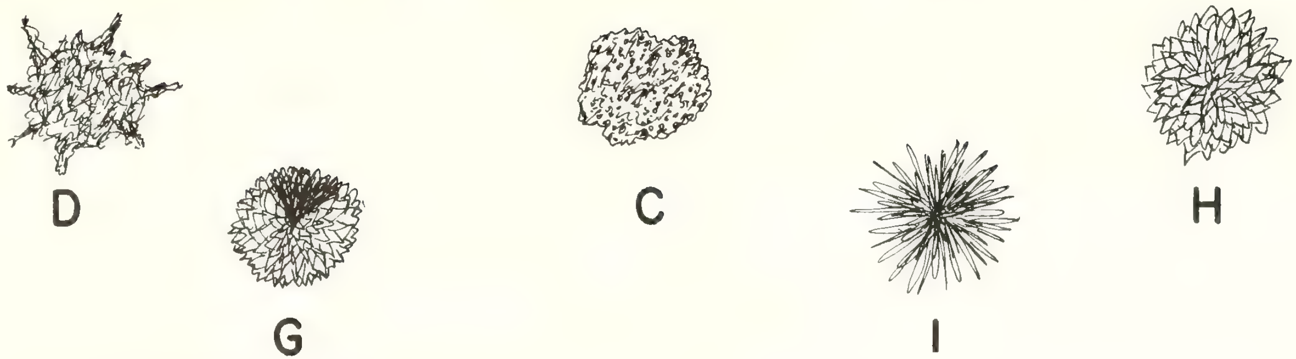
[1] As agreed upon by all three interpreters during the initial work based on large-scale color transparencies taken during the summer months. An asterisk in the left corner of the block indicates those descriptions where all three interpreters did not agree. In these cases, the most common description is listed.



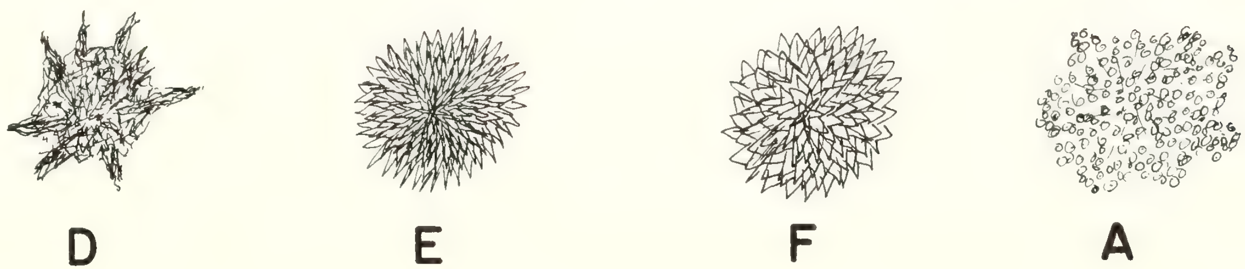
E-1. Kodak Ektachrome, MS 2448, scale 1:2400 exposed over the Clearwater National Forest. The four tree species identified by letters in this triplet[1]: *C* represents lodgepole pine, which is scattered throughout the stand and has typically yellowish-green feathery appearance of the foliage. *G* is subalpine fir, which has a distinctly conical shape; all ages are represented. *H* represents Englemann spruce, which can look brown or grey at the apex when the tree has a good cone crop. *I* represents hemlock, which typically has long conical branches radiating from the bole; it often looks like western redcedar. The drawings below the triplet combine the crown margin and foliage characteristics that were determined by the interpreters to best describe that tree species. There was no ground check to verify the identification of these species. The identification of the subalpine fir and lodgepole pine is much more positive than that of the Engelmann spruce and hemlock.

[1] These letters refer to the letters preceding the common name in appendix D.

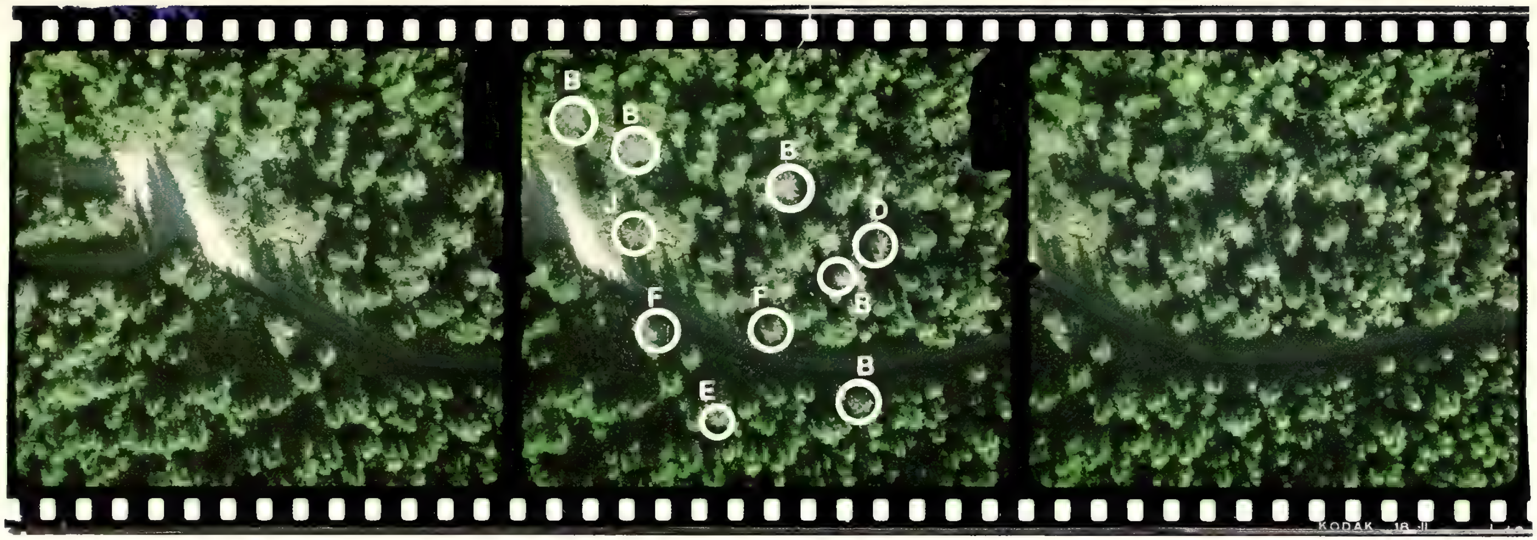


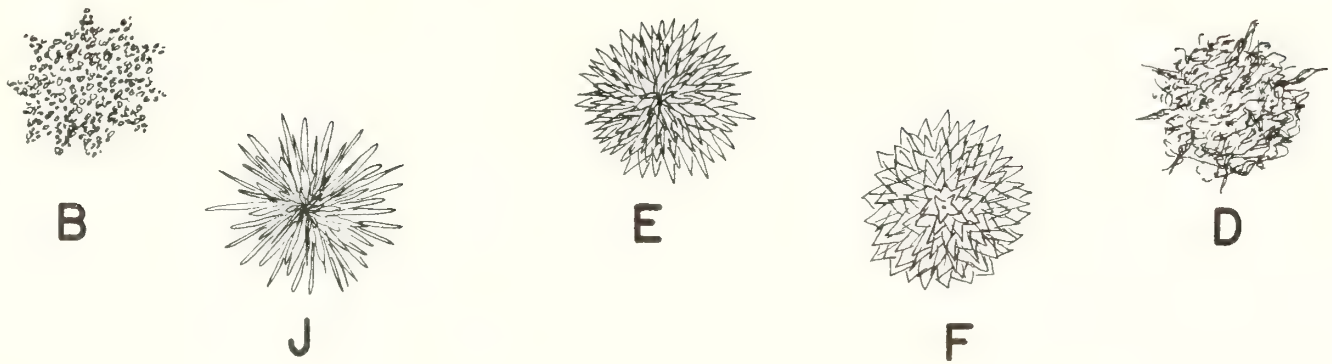


E-2. Kodak Ektachrome, MS 2448, scale 1:2400 exposed over the Clearwater National Forest. The five tree species identified by letters in this triplet: *C* represents lodgepole pine, which is scattered throughout the stand and has typically yellowish-green feathery appearance of the foliage. *D* represents larch, which always has a very fuzzy texture with a few scraggly branches. *G* is subalpine fir, which has a distinctly conical shape; all ages are represented. *H* represents Englemann spruce, which can look brown or grey at the apex when the tree has a good cone crop. *I* represents hemlock, which typically has long conical branches radiating from the bole; it often looks like western redcedar. The drawings below the triplet combine the crown margin and foliage characteristics that were determined by the interpreters to best describe that tree species. There was no ground check to verify the identification of these species. The identification of the subalpine fir and lodgepole pine is much more positive than that of the Engelmann spruce and hemlock.



E-3. Kodak Ektachrome, MS 2448, scale 1:1600 in the St. Joe National Forest. The four tree species identified by letters in this triplet: *A* represents ponderosa pine whose clumps can be readily seen at this scale; note the variation in color. *D* represents larch, which is always fuzzy in texture. *E* represents Douglas-fir, which had the most variable characteristics. *F* represents grand fir, which was consistently the easiest tree to identify. The drawings correspond to the distinguishing crown margin and foliage characteristics by which the tree was described. These trees were ground checked.





E-4. Kodak Ektachrome, MS 2448, scale 1:1600 in the St. Joe National Forest. The five tree species identified by letters in this triplet: *B* represents western white pine, which can be identified as a pine and is normally very blue in color. *D* represents larch, which is alway fuzzy in texture. *E* represents Douglas-fir, which had the most variable characteristics. *F* represents grand fir, which was consistently the easiest tree to identify. *J* represents cedar, which has a very strong star appearance with a slight brown tint. The drawings correspond to the distinguishing crown margin and foliage characteristics by which the tree was described. These trees were ground checked.

Croft, Frank C., Robert C. Heller, and David A. Hamilton, Jr.
1982. How to interpret tree mortality on large-scale color aerial photographs. USDA For. Serv. Gen. Tech. Rep. INT-124, 13 p. Intermt. For. and Range Exp. Stn., Ogden, Utah 84401.

This paper describes photo interpretation techniques for use in sampling for mortality rates with large-scale aerial photography in the Inland Empire. Specifications are given for 70 mm color transparencies. Equipment needed for interpretation is described. Procedures to be used in interpreting the 70 mm photography are discussed with particular emphasis given to problems of species identification. Time required to interpret a single frame of photography is determined for a broad range of stand conditions.

KEYWORDS: mortality sampling, photo interpretation, 70 mm photography, species identification

The Intermountain Station, headquartered in Ogden, Utah, is one of eight regional experiment stations charged with providing scientific knowledge to help resource managers meet human needs and protect forest and range ecosystems.

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Department of
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Forest Service

**Intermountain
Forest and Range
Experiment Station
Ogden, UT 84401**

General Technical
Report INT-125

April 1982

The Dead Softwood Timber Resource and Its Utilization in the West

David P. Lowery

THE AUTHOR

DAVID P. LOWERY, is a research wood technologist at the Intermountain Station's Forestry Sciences Laboratory, Missoula, Mont. He began his career at the Forest Products Laboratory, Madison, Wis. Dr. Lowery has authored several reports on wood utilization.

RESEARCH SUMMARY

The commercial forest land of the West contains dead timber in large quantities that increase each year because of new insect and disease outbreaks. The salvage and utilization of these dead trees is dependent to a large extent on the deterioration that occurs prior to harvesting.

Wood deterioration progresses at an accelerated rate after the tree's death and is affected by various wood, climatic, and biological factors. The longer the dead trees are exposed to the degrading elements, the lower the quantity and quality of usable material that can be recovered. Prompt salvage of dead trees is necessary if the greatest values are to be obtained.

Studies indicate that dead trees and logs can be used for essentially the same purposes as green trees of the same species: lumber, house logs, posts, poles, firewood, and in the production of pulp, paper, and particle board. The use of dead trees in plywood manufacture is often restricted.

This report summarizes the available information on the deterioration and utilization of the western softwoods.

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INTRODUCTION

A few years ago birds, animals, and a few artists were about the only ones interested in dead trees. Birds and animals use dead trees for dens, nests, resting, and observation posts. Artists see beauty in these lifeless forms and in their difference from the surrounding forest. But today timber owners, land managers, and the forest products industry are interested in harvesting and using dead trees.

Since about 1970 timber supply and demand curves have been drastically altered from their projected patterns due in part to continual erosion of the commercial forest land and increased demand for lumber and other wood products. The change of land from timber production to roads, utility rights-of-way, wilderness, and housing subdivisions has reduced the number of acres available to supply our timber needs. A steadily increasing population requires more and more wood products to satisfy its demand for housing and other necessities. The future wood supply depends, to a certain extent, on improved utilization and processing procedures. This could be done by using all parts of the harvested sawtimber-size trees, or by using the smaller, presently unmerchantable trees and down or standing dead trees that often make up the bulk of the postharvest residue.

The overmature, unmanaged forest stands of the West have been subjected to repeated attacks by insects and diseases (fig. 1). The resulting dead trees, scattered throughout the forest, are often left in the woods after harvesting as the major component of the logging residue. The increased use of these dead trees would extend the timber supply.

This report assembles available information describing the dead timber resource, summarizes research on its utilization, and discusses factors to be considered in processing this material.

Figure 1.—The forests of the West contain many trees killed by insects and disease.

THE DEAD TIMBER RESOURCE

The volume of dead timber in the Nation's forests is enormous and estimates as the exact amount are quite variable. Perhaps the best procedure for obtaining a reliable estimate is to use annual data of trees killed by insects, disease, fire, or windthrow. In 1976, mortality on the National Forests' commercial timberland amounted to over 1 billion cubic feet (28.3 million m^3) of growing stock, including 4.4 billion board feet (1.263 million m^3) of sawtimber. This volume is equivalent to slightly more than one-third of the 1976 softwood removal from National Forest lands (USDA 1977). The annual mortality on the commercial forest land on western forests is shown in table 1.

Table 1.—Annual tree mortality for hardwoods and softwoods on the commercial timberland of the public and private commercial forests of the Western States, 1976 (source: USDA, Forest statistics of the U.S., 1977)

State	Growing stock		Sawtimber	
	M ft³	*M m³*	*M bd.ft.*	*M m³*
Oregon	427,500	12 098	1,979,400	568 088
Washington	345,400	9 775	1,696,200	486 809
California	143,000	4 047	791,200	227 074
Idaho	123,365	3 491	561,172	161 056
Montana	130,063	3 681	460,066	132 039
Utah	53,526	1 515	191,387	54 928
Wyoming	42,055	1 190	152,608	43 299
Colorado	91,943	2 602	328,536	94 290
Arizona	15,133	428	68,265	19 592
New Mexico	36,127	1 022	134,727	38 667
Nevada	1,727	49	9,419	2 703
South Dakota	3,791	107	16,645	4 777
TOTAL	1,413,630	40 005	6,389,625	1 833 822

Although all species are susceptible to insect and disease attack, the western species most attacked are Douglas-fir (*Pseudotsuga menziesii* [Mirb] Franco), lodgepole pine (*Pinus contorta* Dougl.), western white pine (*Pinus monticola* Dougl.), ponderosa pine (*Pinus ponderosa* Laws.), and the true firs (*Abies* sp.). Bark beetles are responsible for most of the dead trees. In Montana, northern Idaho, and northeastern Oregon, the mountain pine beetle (*Dendroctonus ponderosa* Hopk.) is killing large numbers of lodgepole and western white pine trees. Catastrophic losses that result in concentrations of dead trees can become a focal point for salvage efforts. However, much of the endemic mortality on the National Forests occurs in unroaded areas, inaccessible to logging. In addition, the mortality is scattered over large areas, which hinders prompt detection and removal. Theoretically, if all the mortality could be salvaged, the annual timber supply could be increased by about 45 percent; but only about 28 percent of the dead timber is both accessible and marketable, and only 10 percent is salvaged each year.

Depending on climate and environmental conditions, dead trees may be a major component of the green timber stand at the time of harvest. West of the coastal mountain ranges, the deterioration rate of downed trees by fungal action is often slowed due to the extremely wet conditions. East of the Cascades and extending into Montana, the lack of moisture and the relatively low ambient temperature at the higher elevations act to restrain the degrading process. As a result, dead timber accumulates in the western forests and, unless removed with the green trees, becomes a highly visible segment of the postharvest residue (fig. 2). Figure 3 shows those factors that affect the volume of dead timber in the western forests.

Figure 2.—Standing and down dead trees are often not removed during harvesting.

Deterioration of Dead Trees

The value of dead timber and its suitability for manufacture is largely dependent on the amount of deterioration that has occurred prior to harvesting. Deterioration usually starts shortly after the death of the tree and progresses through the years until the wood elements are once again incorporated in the soil.

Three groups of biological agents—insects, stain, and decay fungi—are responsible for deterioration of woody tissue. Generally, insects and stain fungi initiate the breaking down of newly killed trees, and conditions are favorable for their attack only in the first few years after death (Furniss 1937). Decay fungi complete the deteriorating process over an extended period.

Figure 3.—Factors that increase and decrease the number of dead trees in the western National Forests.

Among those factors that influence the rate of deterioration by the biological agents are the tree characteristics and the environment. Wood characteristics nclude species, size of tree, amount of sapwood and ıeartwood, rate of growth, age of tree, and moisture content (Beal and others 1935).

The rate of deterioration is influenced by the rate of moisture loss. Rapid moisture loss prevents attack by nsects, stain, and decay fungi; however, slow moisture oss permits attack by these biological agents. The loss of moisture, whether rapid or gradual, causes the dead tree to shrink in size and develop seasoning checks or ongitudinal openings in the wood surface. These checks reduce the quantity and quality of solid wood products that can be obtained from dead trees (Keepf 1978). The openings also often serve as focal points for fungal attack, thereby hastening the deterioration.

Some tree species are inherently more durable or more resistant to deterioration than other species. In general, hose species with a distinct color differentiation between the heartwood and sapwood are the most durable. In the Northwest, western redcedar (*Thuja plicata* D. Donn) and the other cedars are very durable. Douglas-fir and western larch (*Larix occidentalis* Nutt.) are the next most durable. A general durability classification system developed at the USDA Forest Products Laboratory (Hunt 1941) groups the Northwest softwood species as follows:

Class I	Heartwood very durable CEDARS
Class II	Heartwood durable DOUGLAS-FIR (DENSE)
Class III	Heartwood intermediate in durability DOUGLAS-FIR (UNSELECTED) WESTERN LARCH
Class IV	Heartwood intermediate with classes III and V WESTERN HEMLOCK (*Tsuga heterophylla* Sarg.) PINES SPRUCES (*Picea* spp.)
Class V	Heartwood low in durability FIRS

The sapwood of all species is low in durability (USDA 1935). In the living tree, sapwood contains living cells, and at the time of death, the cell contents become a food source for insects and stain fungi. On the other hand, most of the cells in the heartwood are dead and the cell contents consist of extractive and extraneous material. As a result, old-growth trees of large diameter that have a relatively narrow sapwood band surrounding a large amount of heartwood are more durable than younger, second-growth trees that usually have large sapwood bands and relatively small amounts of heartwood (Wright and Harvey 1967). In addition, trees with wide growth rings are less durable than narrow growth-ringed, slow growing trees (Kimmey and Furniss 1943).

The moisture content of the wood is also a major factor in deterioration. Optimum moisture content ranges for insect and fungi growth are somewhat restricted, and the duration of optimum conditions may be an additional growth limitation. The lower moisture content for optimum fungus development is about 27 percent, and fungal growth ceases when the moisture content falls to about 20 percent (Boyce 1948). In the coastal area, moisture content is rarely a limiting factor. Wet wood will support fungus until all or most of the oxygen is displaced by water; however, the wood in a standing tree absorbs very little moisture in the first few years after death even in a wet climate. Where the climate is dry, the moisture content soon falls below the limits for decay in the upper part of the bole. At high elevations and on some eastern slopes deterioration is considerably retarded, and in some localities decay is essentially arrested except at the base of the tree where ground moisture is available.

Dead trees that fall generally break at or near the ground line where moisture from the soil has moved into the wood and created conditions favorable for the growth of decay fungi. After falling, such trees may remain sound and usable for some time, especially if they are kept from contacting the ground, supported by other trees or forest debris.

The Rocky Mountain and Northwest regions possess a variety of geographical features that have a distinct effect on the local environment. West of the coastal mountain range the temperatures are relatively mild and rainfall is abundant, whereas east of this range temperatures are more variable and rainfall more moderate.

Temperature conditions alone, in addition to influencing the percent moisture content, can also affect the deterioration rate. Optimum temperature for wood destroying fungi ranges from 68° to 97° F (20° to 36° C), and the maximum temperatures permitting growth vary from 11° F (6° C) to as much as 25° F (16° C) above the optimum (Cartwright and Findlay 1934; Humphrey and Siggers 1933).

The cause of death and the position of the tree are other factors affecting the deterioration rate. Trees killed by bark beetles that burrow in the cambial layer often slough their bark earlier than trees killed by other agencies. As mentioned earlier, downed trees in contact with the ground are usually at a higher moisture content, thus favoring the growth of decay fungi. Standing trees, on the other hand, may dry out rather rapidly and the lower moisture content retards or prevents the growth of stain and rot fungi, especially in the upper tree parts.

Dating Tree Death

Since deterioration of dead trees is time related, prompt use is necessary for recovering maximum values. Dating the year of tree death is thus an important consideration affecting the tree's potential use. Studies show that changes in the tree's appearance can be used to date the time of death reasonably well for the first 5 years. The indicators generally used are: needle coloration and retention, twig and small branch retention, large branch retention, bark retention, top appearance, and presence of fungal fruiting bodies or sporophores.

Following death, the needles lose their green color and become dark or reddish-brown. Within 2 years, most of the needles and some of the finer branches have been lost from the tree. Larger branches start to break off after 3 to 5 years. The bark is the next part to slough from the tree. After 6 to 8 years, about half of the dead trees have broken tops. Fruiting bodies often develop after 5 years. Combinations of these indicators can be used to estimate the time of death within narrow limits.

Tegethoff and others (1977) used the following criteria to classify dead lodgepole pine in southeastern Idaho:

1-3 years dead: foliage bright orange to straw-colored to gray; some foliage lost.

3-5 years dead: no foliage and most of the small twigs that supported the needle fasicles lost.

5+ years dead: no small twigs and bark peeling.

Cole and Amman (1969) studying lodgepole pine killed by the mountain pine beetle in western Wyoming and eastern Idaho developed these guides:

Killed in current year: green foliage, fresh boring frass, eggs or larvae present.

Killed in previous year: foliage bright orange to straw-colored.

2 years dead: foliage dull orange and most of foliage retained on tree.

3 years dead: foliage dull orange to gray and most of foliage lost from tree.

4 years dead: no foliage and most of the twigs that supported the needle fasicles also lost.

5+ years dead: bark peeling.

Changes in Douglas-fir in western Oregon and Washington have also been reported (Wright and Wright 1954; Wright and Harvey 1967). The 1954 study used the following system:

1-3 years dead: no foliage but smallest branches retained on tree. May have many sporophores (*Polyporus volvatus* Pk.) small, whitish to buff colored and somewhat globose.

3+ years dead: small branches fallen, examination of wood to determine extent of deterioration necessary.

Indicators used by Wright and Harvey (1967) were:

1 year dead: foliage all present to all gone but red; blue stain and fresh *Polyporus volvatus* conks present.

2-3 years dead: no foliage; 60-90 percent of twigs and small branches (less than 3/4 inch [1.9 cm] in diameter) present; *P. volvatus* conks dried; rudimentary *Fomes pinicola* conks.

4-5 years dead: 40-75 percent of twigs and small branches present; 50-90 percent of larger branches (3/4 inch [1.9 cm] and over in diameter) present; some breakage in top one-fourth of crown; *P. volvatus* conks sloughed, *F. pinicola* conks bracket-shaped with reddish margin.

6-8 years dead: 0-15 percent of twigs and small branches present; 30-60 percent of large branches present; bark sloughing and cracking in top 25 ft (7.6 m); upper half of about 50 percent of trees broken off; *F. pinicola* conks often very large.

9-10 years dead: 10-50 percent of large branches present; considerable cracking and sloughing in top 50 ft (15.2 m) of unbroken boles; upper two-thirds of 75 percent of trees broken, others have some breakage; *F. pinicola* conks very large and conks of other fungi present.

Guides for western hemlock and western redcedar in łlaska have been reported by Embry (1963). His system is ıs follows:

<5 years dead: western hemlock, needles nearly gone; mall branches 25 percent gone; secondary branches 0-5 percent gone; western redcedar, needles 50-100 ercent gone; small branches 25-100 percent gone; econdary branches 0-50 percent gone; primary branches -25 percent gone.

6-9 years dead; western hemlock, no needles; small ranches 50-100 percent gone; secondary branches 25-00 percent gone; primary branches 25-50 percent gone; ark partly gone; stem 0-25 percent gone; *F. pinicola* onks present; western redcedar, no needles, small ranches 50-100 percent gone; secondary branches 25-00 percent gone; primary branches 25-100 percent gone; ark 0-25 percent gone; bole 0-25 percent gone.

ase Studies of Tree Deterioration

The deterioration of beetle-killed Englemann spruce *icea engelmannii* Parry) and lodgepole pine in the ountains of western Colorado has been reported by inds, Hawksworth, and Davidson (1965) and of Engelann spruce in Utah by Mielke (1950).

Most of the Colorado mortality occurred between 1943 ıd 1945, and the decay volume was measured at 5-year tervals through 1961. The study results indicated the ecay volume of Engelmann spruce averaged about 11 ercent of the gross cubic foot volume in the sampling ears. Most volume loss was attributed to sapwood rots at were defined as decays that went from the outside the trunk and progressed inward. Such rots usually arted at the base of the tree or in the roots. Moisture ontent determinations showed that the upper part of the ole was about 20 percent and the lower portions of the em had moisture contents between 50 and 100 percent. e higher moisture content favored the growth of the ecay fungi and the location of the rot increased the ossibility of the trees being windthrown. A windthrow end line for all plots indicated that about 8 percent of e volume had been windthrown 10 years after peak ortality and 28 percent after 20 years. Fallen trees ecay rapidly and the rate was about twice as fast for ees in contact with the ground. Infections in the owned trees usually started around drying checks where oisture accumulated. In one study area lodgepole pine counted for about two-thirds of the trees killed by etles in 1946. The volume of blue-stained wood and the te of decay for this species was about the same as for ıgelmann spruce in the same area. Windthrow loss was ghtly less than for spruce; however, projected windrow loss indicated about 45 percent of the lodgepole lume would be on the ground in 20 years. Decayed ots were responsible for about 44 percent of the windrown trees.

Mielke's study (1950) of the beetle-killed Engelmann ruce in Utah showed that, after 25 years, 84 percent of e dead spruce trees of all sizes were still standing. Of ose trees that had fallen, a higher percentage were of e smaller size classes. Decay fungi and root and basal ts were responsible for felling 77 percent of the downed trees. The decay rarely extended more than 1 to 2 ft (0.3 to 0.6 m) above ground level. In downed trees decay usually started a few years after they fell, especially if the trees contacted the ground. In trees supported off the ground, decay usually started around seasoning checks where rainwater collected. At high elevations summer rains required for favorable decay conditions occur only occasionally so the rate of deterioration is slow. The moisture content of trees dead for 3 years or longer was less than 22 percent, too low for fungi to grow. On the study area the dead trees dried fairly rapidly, often starting to check while the needles were green. Examination of logs cut from the dead trees indicated 65 percent had a single large check, 15 to 20 percent had two checks, and occasional trees, three checks. About 15 percent of the trees developed numerous small checks but no large ones. Data obtained in this study indicated that beetle-killed spruce in Utah could remain standing for more than 20 years.

The work of Lyon (1977) indicated that lodgepole pine trees, fire-killed in western Montana, have variable rates of attrition depending largely on diameter. The first 2 years after the fire, very few trees were felled but the average annual attrition rate for the next 13 years was 13.4 percent. Snags smaller than 3 inches (7.6 cm) in diameter had an attrition rate of 27.9 percent, trees 3 to 8 inches (7.6 to 20.3 cm) in diameter had a rate of 8.4 percent, and trees larger than 8 inches (20.3 cm) had a sporadic attrition rate. Some of the larger trees would probably stand indefinitely.

Wagner and Offord (1972) studied the deterioration of logging slash in northern California. They indicated that the major factors influencing the rapidity of the slash breakdown were climatic (precipitation, temperature, insolation, and soil moisture) and biologic (tree species and decay fungi). Temperature and moisture records from near the study areas indicated high summer temperatures and low wood moisture contents limited the growth and spread of common decay fungi. An interval of 30 years was needed to reduce the fire hazard from extreme to a rating comparable to that of the prelogged condition; 43 percent of the original slash volume remained after 29 years.

Another California study (Kimmey 1955) reported on the deterioration of fire-killed trees of species such as ponderosa pine, Jeffrey pine (*Pinus jeffreyi* Grev. and Balf.), sugar pine (*Pinus lambertiana* Dougl.), Douglas-fir, and white fir (*Abies concolor* [Gord. and Glend.] Lindl.). Fungi and insects were the principal deterioration agents. Deterioration started the first year after death with blue stain developing under the bark. Additional staining and incipient decay occurred in the sapwood during the second year, and after 3 years the sapwood was no longer salvable; only the larger trees had sufficient sound wood to justify salvage. Although the white fir did not stain extensively, it was severely decayed by the end of the second year. After 3 or 4 years even large logs of this species were beyond salvage. Ponderosa and Jeffrey pines, both with thick sapwood, had slower deterioration rates than fir. However, few logs would be salvageable after 5 years. Sugar pine had a thin sapwood

and a relatively durable heartwood. Large logs of this species could be salvaged 10 years after the fire. The heartwood of Douglas-fir decayed slowly in old trees so that large logs could probably be used 15 to 20 years after death. Other study results indicate that heartwood deterioration was faster in trees with wide growth rings, and younger trees deteriorated faster than older trees under the same conditions.

The rate of deterioration of beetle-killed Pacific silver fir (*Abies amabilis* Forbes.) was studied by land managers in the Northwest (Wright and others 1956). The study showed that this species deteriorates at a rate of 5 percent or more of the total volume up to 4 years after death. However, log scale deductions for rot were 30, 39, and 54 percent for logs from trees dead 2, 3, and 4 years, respectively. Observations indicated that younger trees of smaller diameter would probably deteriorate more rapidly than older, larger trees because of the greater proportion of sapwood.

A virgin timber blowdown area on the Olympic Peninsula in Washington was the site of a long-term study (Boyce 1929; Buchanan and Englerth 1940). Observations were made annually for the first 4 years following the catastrophe, and at 5, 10, and 15 years detailed examinations were made of five tree species—Douglas-fir, western redcedar, silver fir, sitka spruce (*Picea sitchensis* [Bong.] Carr.), and western hemlock. For the first 3 years ambrosia beetles and blue stain attacked and degraded the sapwood of all species. From the fourth year on decay organisms became increasingly important so that 5 years after the blowdown virtually all the sapwood of all species had been destroyed, as well as considerable heartwood of the less durable species, silver fir, western hemlock, and Sitka spruce (table 2). Western hemlock and silver fir, the two species with the greatest percentage of sapwood and the least durable heartwood, decayed most rapidly. These species were made worthless after about 8 years. There was little difference between the heartwood and sapwood of Sitka spruce, and all sound wood of this species was destroyed in 15 years. The sapwood of Douglas-fir deteriorated rapidly but the heartwood was much more durable. Trees 30 inches (76.2 cm) and larger in diameter had a considerable volume of usable heartwood after 15 years. Western redcedar was the most durable species, having lost only its sapwood in the study period.

Table 2.—The percentage of board foot and cubic foot volume loss for five Olympic Peninsula tree species after 5 years (source: Boyce 1929)

Species	Percent of loss	
	Bd.ft.	*Ft³*
Western redcedar	26.5	22.0
Douglas-fir	34.5	34.2
Sitka spruce	46.3	41.7
Silver fir	73.5	55.8
Western hemlock	91.9	68.4

Defect

The occurrence and type of defect can have a profour effect on the use of dead trees. Spiral checks and splits may prevent the use of these logs for lumber manufacture or severely reduce grade recovery. Rot and fire scar affect the pulp chip yield. Drying of the wood and the development of defects start shortly after the tree dies, and defect severity increases with time. Table 3 shows the frequency of defect occurrence in samples of green and dead lodgepole and western white pine trees selected for sawmilling studies. The lodgepole pine trees (1,568) were taken from south-central Montana and the western white pine trees from north-central Idaho. In general the data show that breaks, checks, spiral check splits, and rots occur more frequently in dead trees thar in green trees.

Characteristics of Deadwood

The processing and use of many species depends to a large extent on the inherent physical and mechanical properties as well as the chemical constituents of the wood. For dead tree wood, an understanding of these characteristics and knowledge of the differences between dead and green tree wood are essential for its utilization. Although no exhaustive evaluation of dead tree wood has been made, the following information has been obtained for lodgepole and western white pine. It i believed that the conclusions based on this information are generally applicable to wood obtained from dead trees of other western softwood species.

The physical characteristics of dead tree wood are only slightly affected by long-term exposure in the fores After the bark sloughs from the tree, the exposed wood surface gradually assumes the gray color characteristic of unprotected wood. This change in color is due to oxidation, leaching of extractives, and deposition of dust and dirt. These same factors are responsible for the los of the wood's normal odor and taste.

When dead tree logs are milled, the wood does not have the usual luster associated with freshly cut green wood. This difference may be due to the dead log's low moisture content, which results in a greater tearing of t fibers on the surface.

The weight of dead wood is also affected by its moisture content, which decreases with time. Lowery a Hearst (1978) reported average moisture content of 16.5 and 23.7 percent for lodgepole and western white pine lumber, respectively, cut from dead tree logs. The resul of specific gravity determination on the same sample material indicated no significant difference from the specific gravity of green wood. The specific gravity determinations were based on green volume and ovendry weight.

A few of the mechanical characteristics have also been studied. Gernert and others (1980) reported on the percent shrinkage and specific gravity for three types of western white pine wood. They found no significant differences between the shrinkage characteristics and specific gravity for live, dead down, and dead standing western white pine trees. Lowery and Pellerin (1982),

Table 3.—*Distribution of scaling defects by number and percentage for lodgepole pine in Montana and white pine from north Idaho (source: Unpublished data USDA Forest Service, Region 1, Missoula, Mont.)*

Defect	Belgrade lodgepole pine						Dillon lodgepole pine				Western white pine					
	Green		Red needled		Dead, down and standing		Green		Dead		Green		> 90% bark retained		< 90% bark retained	
Break[1]	14	(4.0)[2]	6	(3.0)	9	(1.9)	4	(1.8)	8	(2.0)	84	(34.5)	95	(23.1)	75	(14.7)
Crook	159	(45.2)	75	(37.1)	49	(10.2)	74	(33.3)	41	(10.0)	8	(3.3)	—		4	(0.8)
Ringshake	1	(0.3)	—		—		1	(0.5)	—		5	(2.1)	2	(0.5)	1	(0.2)
Checks	3	(0.9)	56	(27.6)	326	(68.1)	6	(2.7)	255	(62.2)	19	(7.8)	203	(49.3)	253	(49.3)
Spiral checks	—		9	(4.5)	—		—		22	(5.4)	—				4	(0.8)
Split	1	(0.3)	3	(1.5)	—		—		—		—		1	(0.2)	2	(0.4)
Rot	44	(12.5)	18	(8.9)	56	(11.7)	54	(24.2)	29	(7.1)	65	(26.8)	54	(13.1)	100	(19.5)
Void	8	(2.3)	1	(0.5)	7	(1.5)	74	(33.3)	47	(11.3)	53	(21.8)	54	(13.1)	73	(14.3)
Pitch seam	—		—		—		5	(2.3)	5	(1.2)	6	(2.5)	2	(0.5)	—	
Sucker limb	—		3	(1.5)	—		—		—		1	(0.4)	1	(0.2)	—	
Catface	80	(22.6)	21	(10.4)	26	(5.4)	—		2	(0.5)	2	(0.8)	—		—	
Butt swell	12	(3.4)	3	(1.5)	2	(0.4)	—		—		—		—		—	
Sweep	30	(8.5)	2	(1.0)	4	(0.8)	3	(1.4)	1	(0.3)	—		—		—	
Knots	—		5	(2.5)	—		—		—		—		—		—	
Holes	—		—		—		1	(0.5)	—		—		—		—	
Total defects:	352	(100.0)	202	(100.0)	479	(100.0)	222	(100.0)	410	(100.0)	243	(100.0)	412	(100.0)	512	(100.0)
No trees	472				468		277		351		68		54		54	

[1] Does not include logs lost due to breakage.
[2] Numbers in parentheses are percentages.

studied the destructive and nondestructive bending strength properties of lodgepole and western white pine dimension lumber. Again, the data indicated that there was no significant difference between the modulus of elasticity and the modulus of rupture of green wood and deadwood of these species.

Lieu and others (1979) studied the chemical characteristics of dead and green lodgepole and western white pine. Heartwood and sapwood from green, dead down, and dead standing trees were analyzed. The average percentage of cell wall components, holocellulose, alpha cellulose, hemicellulose, and Klasen lignin, were very similar. There was no significant difference between the green and dead tree samples nor between the heartwood and sapwood samples. These researchers also reported the combustion characteristics of the same wood types, as did Kelsey and others (1979). The higher heating values for the samples studied were essentially the same. The major discrepancy between the green wood and deadwood data was in the percent ash content —the dead trees had greater absolute amounts of ash than did the green trees.

These studies indicate that deadwood characteristics do not differ significantly from green wood. In addition, no obvious insurmountable difficulties were encountered in making particle board from deadwood flakes and urea-or phenol-formaldehyde adhesives (Mueller 1959; Maloney and others 1976). However, other investigations indicate that the machining, milling, or chipping of dead tree wood requires more energy than the processing of green wood (Lowery and others 1977; Maloney and others 1976).

SELLING METHODS

The usual method of selling timber from Federal Government land applies a set price per thousand board feet to the log scale volume of each species removed. When the value of the logs is relatively high, or when the various species have different values, this method has proved equitable to both buyer and seller. However, when timber values are low and the cost of preparing and administering the sale exceeds the potential return, other methods may be used.

Combes (1978) discusses some of the problems encountered in appraising and selling dead timber and presents methods for overcoming these problems. According to Combes, more mill cost studies are needed to develop the appraisal method that would best be applicable for all dead timber situations.

Some of the alternative sales methods used with dead timber are lump sum, piece rate, per acre, per ton, or per cord. In a lump sum sale, a particular quantity of timber is sold for a price set prior to harvesting. In some instances, dead trees may also be sold by the piece. A sales procedure developed in the Pacific Northwest region has been termed PAM (per acre material) (Hamilton and others 1975), where the purchaser pays a fixed amount for the material on each acre. This system was devised initially to sell postlogging residue, but it can also be used to sell dead timber. The purpose of PAM is to encourage the buyer to remove the low-valued material on a logged area rather than leave it for disposal. The principal advantage of PAM is that sale costs are minimal.

Green and dead timber have also been sold on a weight, cubic volume, or cord basis. When mixed stands of green and dead are sold by weight, the weight of each type is prorated to obtain an average that can be used for the entire sale. The weight of truckloads of dead tree logs typically ranges from about 31,000 to 43,000 lb (14 091 to 19 545 kg). Although the present practice is not to scale the loads of dead trees as sawlogs, a few such loads have been scaled in the past as shown in table 4. These data also illustrate the effect on lumber recovery of defects present in dead tree logs, the difference between gross and net log scales. Many dead tree logs are chipped for pulp rather than sawed into lumber, in which case only two defects, rot and fire scar or charcoal, are considered important. The cull for these defects is usually less than 10 percent.

When dead timber is to be converted into pulp chips, the cubic volume measurement may be used. The relationship between weight and cubic volume is established by first weighing the truckload of logs and then measuring the individual logs in sample loads (table 5). The cubic volume in feet can be computed using Smalian's equation:

$$\text{Volume} = 0.002727\,(D_1^2 + D_2^2)L$$

where:

volume is in cubic feet

D_1 and D_2 are end diameters in inches

L is length in feet.

About 1 percent of the load volumes was considered cull because of rot.

In some instances the cubic volume has been converted to cords using a conversion factor of 86.6 ft^3 (2.45 m^3) per cord. Pulp and paper plants frequently use this measurement.

Table 4.—Weight, scale, and number for typical loads of dead lodgepole pine logs (source: Targhee National Forest, St. Anthony, Idaho)

Load	Load weight	Gross scale	Net scale	No. of logs
	Lb	*M bd. ft.*	*M bd. ft.*	
1	36,440	4.29	0.80	77
2	40,380	5.30	1.22	63
3	38,260	5.12	0.97	64
4	41,400	5.55	1.16	80
Average	39,120 (17 782 kg)	5.07 ($1.46 m^3$)	1.04 ($0.30 m^3$)	71

Table 5.—Weight, cubic foot volume, and number for typical loads of dead lodgepole pine logs (source: Lolo National Forest, Missoula, Mont.)

Load No.	Weight	Volume	Weight	No. of pieces
	Lb	*Ft^3*	*Lb/ft^3*	
1	38,160	1,020	37.4	85
2	44,440	1,199	37.1	84
3	39,120	1,136	34.4	69
Average	40,573 (18 442 kg)	1,118 ($31.64 m^3$)	36.3 ($582.23 kg/m^3$)	79

UTILIZATION OF DEAD TREES

The preceding sections have indicated, on the basis of wood characteristics, that there are no restrictions limiting the use of dead tree wood. However, the appearance and defects of dead trees and logs often inhibit the use of this material for specific purposes. Lower quality or reduced quantity may be the principal deterrents. Various possible uses are presented in the following sections.

Lumber

One of the highest value products most commonly associated with trees is lumber (fig. 4). A number of studies have sought to determine the quantity and quality of material obtained from dead trees of different species, and to compare these values with determinations obtained from matched samples of green tree logs. All the studies indicate that dead trees can be used for lumber production. However, the lumber recovered from such trees is lower in quantity, quality, and value (with a few exceptions) than lumber made from comparable green trees. A greater loss in volume due to breakage is incurred in the felling and handling of dead trees and logs. Decay and borer damage in the sapwood and soil embedded in the outer wood of barkless trees may require heavy slabbing and greater cull board production.

Figure 4.—Decks of dead tree logs before being processed into dimension lumber and pulp chips.

The studies also show that if lumber quality is to be maintained, prompt salvage of dead trees, before complete foliage loss, is necessary. Usually the best and highest valued boards are cut from the clear wood immediately under the bark. This wood is also most readily attacked by decay and stain fungi and wood-boring insects. Lumber made from the inner part of the log often contains knots or other degrading features. As long as the bark remains intact on the dead trees, lumber quality decreases slowly, but after about 5 years the bark sloughs, deep checks develop, and the rate of quality decline increases. Quality and quantity have a direct effect on the value of lumber made from dead tree logs. As the time since death lengthens, the value of the lumber produced from the dead trees decreases.

A discussion of the study results by species follows.

Lodgepole Pine

The results of lumber grade-yield studies for this species have been reported by Carr (1978)[1] and Dobie and Wright (1978b). Carr summarized studies made on three National Forests in Montana—Bitterroot, Gallatin, and Beaverhead. The Bitterroot study used green and dead trees obtained from a decadent, old-growth stand. The dead component included a wide variety of natural mortality quality classes, from the recently dead to downed trees. Both dimension and boards were cut from the study logs.

In addition to the green, control logs, the Gallatin study included green-needled trees that showed signs of medium to heavy bark beetle infestation; red-needled trees, dead less than 3 years; and trees dead longer than 3 years. Only 1-inch (2.5-cm) thick lumber was produced in this study.

The Beaverhead study trees were either green or dead, and the dead included a few red-needled trees and others taken from the ground. Primarily, dimension lumber was produced from the study logs. All the study logs had a minimum small end diameter of 5.6 inches (14.2 cm), a minimum length of 8 ft (2.4 m), and were at least one-third sound. A summary of the study results is shown in table 6.

able 6.—Comparison of grade-yield studies using green and dead lodgepole pine logs obtained from three National Forests (source: Carr, W. R. 1978)

Study	Percent dimension lumber	Value per M bd.ft. lumber tally	Percent lumber recovery	Value per M net log scale
		Dollars		*Dollars*
itterroot				
Live	41	221.99	150	332.98
Dead	60	150.41	134	201.55
iallatin				
Live	0	261.53	121	316.45
Dead	0	199.81	114	227.78
leaverhead				
Live	89	177.53	172	305.35
Dead	91	161.82	150	242.73

The summary shows that dead trees have value when used in lumber production. The quality of lumber made from green and dead trees is reflected in the value per thousand board feet (M bd.ft.) lumber tally. Obviously, a lower quality of lumber is produced from the dead tree logs. The differences between values ranged from $15.71 per M bd. ft. for the Beaverhead study to $71.58 per M bd.ft. for the Bitterroot study. The summary also shows that the highest values were obtained when lumber 1 inch thick (2.5 cm) was produced (Gallatin study). The percent lumber recovery indicates a smaller quantity of lumber was made from the dead tree logs than from the green tree logs. Just as the increased number of kerfs required to produce lumber 1 inch thick (2.5 cm) reduced the percent lumber recovery in the Gallatin study; so also, the increased number of defects in the dead logs reduced the percent lumber recovery in all the studies. The value per thousand board feet net log scale indicates both the quality and quantity of lumber produced from the green and dead logs.

Another mill-scale study (Plank 1979) used 267 live and dead lodgepole pine in Wyoming—120 live and 147, or about 55 percent, dead. For the live trees the lumber recovery was graded 47 percent Standard or Better, 17 percent Utility, and 8 percent Economy. For the dead trees only 24 percent was graded Standard or Better, 37 percent Utility, and 13 percent Economy. The lumber recovery from the two tree types, based on gross log cubic volume, was essentially the same—32 and 31 percent for the live and dead samples, respectively.

In a Canadian lodgepole pine study, Dobie and Wright (1978b) used four categories of trees; (1) green; (2) red-needled, some dead more than 2 years; (3) gray with tight bark, probably dead more than 4 years; and (4) gray with loose bark, dead longer than the preceding group. The study results were essentially the same as Carr's. A smaller quantity and lower quality of material was produced from the dead trees than from the green trees. Also, the study indicated that beetle-attacked trees should be harvested prior to foliage loss, if possible. The lowest values and quantities were obtained from those trees dead the longest time.

True Firs

Lumber grade-yield studies using species of the true firs have been made in the United States and Canada (Woodfin 1976; Snellgrove and Fahey 1977; Dobie and Wright 1978a). White fir and grand fir (*Abies grandis* [Dougl.] Lindl.) trees in Oregon killed by the tussock moth were milled after about 2 years, along with a matched sample of green logs. The bark on the dead trees, defoliated by the insect larvae, had begun to loosen. Average diameter at breast height (d.b.h.) for the green trees was 27 inches (68.6 cm) and for the dead trees 24 inches (61.0 cm). About 98 percent of the lumber produced was dimension, 2 inches (5.0 cm) thick, and the remainder was 1 inch (2.5 cm).

[1]Carr, W. R. 1978. Comparison of lodgepole pine lumber recovery from live and dead timber. USDA For. Serv. office rep., Region 1, Missoula, Mont.

The quality and quantity of lumber recovered from the dead trees were affected by the time since death. According to Woodfin (1976), the green trees had a value of $59 per hundred cubic feet and the dead trees $43 per hundred cubic feet. The quality loss was about 27 percent. Also, 51 percent of the dead tree lumber was No. 3 Common, Standard or Better, and 49 percent was No. 4 Common, Utility, and Economy. For the green trees, these percentages were 61 and 34, respectively. The dead trees had a scaling defect of 41 percent and a cubic lumber recovery of 28 percent, as opposed to a scaling defect of 36 percent and a cubic lumber recovery of 32 percent for the green trees.

Alpine fir (*Abies lasiocarpa* [Hook.] Nutt.) was the species used in the Canadian study (Dobie and Wright 1978a). The research objective was to evaluate a system used to separate dead trees into two quality classes: class 1, those with unbroken tops or with tops broken in the stem at a point smaller than 4 inches (10.2 cm) diameter; and class 2, snags with tops broken in the stem at a point larger than 4 inches (10.2 cm) diameter. A total of 100 trees, representing the complete range of merchantable d.b.h., were selected for each quality class. Approximately 99 percent of the lumber produced was dimension, 2 inches (5.0 cm) thick.

This study indicated that the classification system in general distinguished lumber values. The trees in quality class 1 had greater value and produced more lumber than trees in quality class 2. The average value per M bd.ft. of class 1 trees was $152.70, and the average value per M bd.ft. for class 2 trees was $143.40. A comparison of the average percent lumber grade yields for the two quality classes is:

	No. 2 and Better	No. 3	Economy
Class 1	30	46	24
Class 2	20	52	28

The average lumber recovery factor (LRF) or board feet of dry, surfaced lumber per cubic foot for class 1 was 5.3, and for class 2 was 3.8.

Western White Pine

Two studies in northern Idaho sought to determine the value of dead western white pine trees (Snellgrove and Fahey 1977; Snellgrove and Cahill 1980; and Carr 1979[2]).

[2]Carr, W. R. 1979. Comparison of white pine lumber recovery from live and dead timber. USDA For. Serv. office rep., Region 1, Missoula, Mont.

The Snellgrove and Cahill report contains a detailed discussion of the characteristics, problems, and product recovery associated with one dead white pine milling study. The four tree classes used in the study were:

- Live: living green trees
- Class I: dead trees with some brown needle retention
- Class II: dead trees with no needles and 90 percent or more of the bark retained on the tree
- Class III: dead trees with no needles and less than 90 percent of the bark retained on the merchantable portion.

The average d.b.h. of the classes ranged from 20 to 23 inches (50.8 to 58.4 cm). All logs were processed into 1- and 1 1/4-inch (2.5 and 3.2 cm) lumber.

The study results showed that the trees dead the longest time (class III) had the greatest loss of usable wood. The percent loss in volume due to felling, handling, and transporting to and around the mill was as follows:

Determination class	Percent loss
Live	3.5
I	4.6
II	7.7
III	7.9

The tops of the older dead trees have a lower ability to absorb shock and tend to shatter when the trees fall. In addition, smaller amounts, lower grades, and narrower boards are obtained from dead trees. Table 7 is a summary of value, grade yield, and 6-inch (15.2-cm) and narrower board recovery for the different study classes.

The second western white pine study (Carr 1979) had three classes of trees: (1) live; (2) probably dead less than 5 years, 90 percent or more of the bark retained on the tree; and (3) probably dead more than 5 years, less than 90 percent of the bark retained on the tree. All logs were at least one-third sound and were cut into 1- and 2-inch (2.5- and 5.0-cm) lumber. The results, summarized in table 8, showed that the older dead trees had a greater percentage of defective material (gross versus net log scale), and, based on net log scale, a greater percentage of lumber was recovered from these logs. However, the value per M bd.ft. was less and the associated lumber quality was lower. Table 8 shows the summary of log scaling data and lumber grade recoveries for three classes of western white pine trees.

Table 7.—Summary of value, grade yield, and 6-inch and narrower board recovery for different classes of western white pine trees (source: Snellgrove, T. A., and J. M. Cahill 1980)

Deterioration class	Cubic defect	Average value per M bd.ft.	Average value per C ft³	Boards 6 inches and narrower	Lumber grade recovery: Select and clear	Nos. 1, 2, 3 shop	Nos. 1, 2 common	No. 3 common	No. 4 common	No. 5 common
	Percent	*Dollars*	*Dollars*	*Percent*	*Percent*					
Live	9.4	204	104	20	5.12	8.87	26.59	47.16	11.48	0.78
Class I	12.8	160	79	24	1.56	3.10	15.56	54.20	24.16	1.42
Class II	21.2	122	57	27	1.05	5.42	6.95	39.23	42.68	4.67
Class III	24.8	101	44	35	0.31	1.23	1.72	19.46	62.03	15.26

able 8.—Summary of log scaling data and lumber grade recoveries for three classes of western white pine (source: Carr, W. R. 1979)

Tree class	Log scale Gross	Log scale Net	Lumber recovery	Percent of net scale	Value per M bd.ft.	No. 3 clear and better	Shop	5C and better	Standard and better	Utility and economy
	— Board feet —		M bd.ft.	Percent	Dollars	Percent				
ve	51,450	41,900	54,350	129.7	283.95	13.7	9.8	61.4	12.9	2.2
90% bark	40,330	18,420	37,469	204.4	213.73	3.0	5.0	67.8	17.9	6.2
:90% bark	42,910	4,980	41,682	837.0	151.54	0.4	0.4	14.7	36.3	48.2

'onderosa Pine

Lumber recovery from second-growth ponderosa pine 'ees killed by mountain pine beetle in eastern Oregon as been reported by Fahey (1980). Included in the board ıill study were 40 trees in each of five categories— reen, and dead 1, 2, 3, or 4 years; and 30 trees dead ither 3 or 4 years were processed in the stud mill.

Trees cut for boards had a major loss in value within 1 ear with blue stain being the most important loss factor. he recovery of 2 Common and Better lumber decreased 'om approximately 40 percent for the green trees to bout 3 percent for trees dead 1 year or longer. The olume recovery at the stud mill was slightly greater than t the board mill.

As in other species studies, this study also indicated ıat tree and log breakage increased with time since eath.

:ngelmann Spruce

Cahill (1980) compared the lumber recovery from green nd dead Engelmann spruce trees. The results of this rade-yield study closely conform to results of similar tudies of other species. The dead tree logs had a greater ercent overrun, a lower average lumber value, a greater olume of residual material, and a smaller volume of awdust. Table 9 is a summary of the study results.

'ulp and Paper

The deterioration of dead timber may progress to the oint that salvage for lumber manufacture or use in the ound is no longer practical. However, enough sound 'ood may still be present to justify its removal from the orest for use by the pulp and paper or particle board ıdustries. The suitability of insect-killed timber for these ses has been studied by several researchers, and the ulp and paper industry has gained some experience in sing this material when sawmill generated chips have een in short supply (McMichael 1975).

The processing of live, dead down, and dead standing trees of four Rocky Mountain species—lodgepole pine, Engelmann spruce, western larch, and Douglas-fir—has been reported on by Lowery and others (1977). Bolts of each wood type and species were processed through a chipper, and the chip quality and energy required to chip the wood were measured. The percent moisture content of the dead tree bolts was considerably less than for the green tree bolts; this factor was probably responsible for the 30 percent more energy that was required to chip the dead tree bolts than was needed for the green tree bolts. The overall chip quality from all the wood types was good; however, a slightly greater percentage of fines was obtained from the dead tree bolts. No difficulty was encountered in separating the tree bark from the chips. Another section of this report is concerned with the experimental pulping of sound lodgepole pine trees dead for at least 15 years. The tests indicate that pulp made from such material should be suitable for a variety of paper and board products.

This testing confirmed work done earlier by McGovern (1951) with the same species. McGovern's research on several types of green and insect-killed lodgepole pine evaluated physical and chemical tests made on ground wood, sulfite, and sulfate pulping. The deadwood differed little in weight per cord and in density from the green wood, although the deadwood was lower in percent moisture content. The insect-killed wood contained considerable incipient decay. Chemical composition of the two wood types was about the same; however, the deadwood had lower contents of holocellulose and alpha cellulose.

Sulfate pulping tests made on green and sound deadwood had similar pulping characteristics and gave nearly the same pulp yields and pulp strengths. Deadwood with about 28 percent advanced decay showed a slight tendency to pulp more rapidly and to give lower permanganate numbers, lower pulp yields, and lower

'able 9.—Comparison of results for a mill-scale study that used live and dead Engelmann spruce (source: Cahill 1980)

Type	Log scale Gross	Log scale Net	Lumber tally	Volume Log	Volume Lumber	Volume Sawdust	Volume Residual
	— Board feet —			Ft^3 (m^3)			
)ead	74,065	34,835	89,834	13,982 (395.69)	6,462 (182.87)	850 (24.06)	6,670 (188.76)
.ive	14,850	14,185	21,476	2,748 (77.77)	1,547 (43.78)	206 (5.83)	994 (28.13)

pulp strengths. The difference between the green and decayed dead pulps was 5 percent in yield and 10 percent in pulp strength.

Sulfite pulping tests, using green and deadwood, yielded pulps containing large amounts of dark fiber bundles that could be bleached. Again, the deadwood showed a tendency to pulp more rapidly and gave a slightly lower yield. Both pulps had ether solubility values that indicated a potential for pitch problems.

The ground wood pulping tests showed that pulps of good color and strength could be made from both green and dead lodgepole pine with moderate energy consumptions. Under comparable grinding conditions, the green wood pulps were better.

In contrast with the relatively long usability of the Northern Rocky Mountain species, trees in the Pacific Northwest have a relatively short usable life. After 2 years the sapwood of beetle-killed Douglas-fir was no longer suitable for lumber, but after 3 years some recovery of the sapwood for pulp might be possible (Wright and Wright 1954).

Looper-killed western hemlock on Victoria Island, B.C., had deteriorated beyond recovery by the seventh year after death (Engelhart 1957). The deterioration of Pacific silver fir was also fairly rapid. Pulping tests made using beetle-killed fir trees dead more than 2 years showed a decreased yield and impaired pulp strength (Wright and others 1956). After this fir was killed by the balsam woolly aphid, tests showed pulp quality decreased rapidly with increased time after death until an acceptable bleached pulp could not be produced if trees dead for 3 to 5 years were the major wood supply (Shea 1960).

Posts and Poles

Because of their size, straightness, minimum taper, and ease of preservation, green lodgepole pine trees have been preferred for fenceposts, corral rails, and utility poles. These same products when made from dead trees would have a lower moisture content, an advantage that would eliminate a long air-seasoning period, thus reducing the need for a large inventory. This same characteristic indicates lighter weight, hence larger loads and easier treatment.

Post and corral rail specifications are usually developed by the individual treating plants and depend, to a large extent, on local conditions and practices. Appearance is often a major consideration. Pole specifications are published by the American National Standards Institute (ANSI) (1972), and although these specifications do not require the use of living trees, the occurrence and placement of defects may eliminate the use of some dead trees for poles. The preservative treatment of posts and poles is discussed separately.

Posts

Lowery and Host (1979) report on the preservative treatment of posts and poles made from dead lodgepole pine trees. Two treating methods, cold soak or steeping and pressure treatment, were used to treat fenceposts from trees dead for at least 4 years. A total of 85 posts—36 small, 36 large, and 13 control—were used in the steeping study. The peeled, pointed, and capped posts were placed upright in a series of tanks filled 30 inches (76.2 cm) with a 5 percent solution of pentachlorophenol in a light crude oil (fig. 5). Three large posts, three small posts, and one control post, selected at random, were removed from the tanks at 30-minute intervals. Six hours was the longest soak period used.

Figure 5.—Lodgepole pine poles are bath-treated with a preservative.

The study results indicated that none of the treatments gave the minimum retention required by the American Wood Preserver's Association (AWPA) standard (1972) of 0.30 lb lb/ft^3 (4.81 kg/m^3). Also, there was no consistent relation between the length of treating time, the depth of preservative penetration, and the pounds per cubic foot preservative retention.

In the pressure treatment phase of the study, 39 posts from dead lodgepole pine trees were used. An unheated water solution 1.50 to 1.75 percent of fluorochrome arsenate phenol, type B (Osmosalts), was the preservative used and the pressure periods were 15, 30, or 45 minutes (fig. 6). After treatment, all the posts had retentions exceeding the specification requirement.

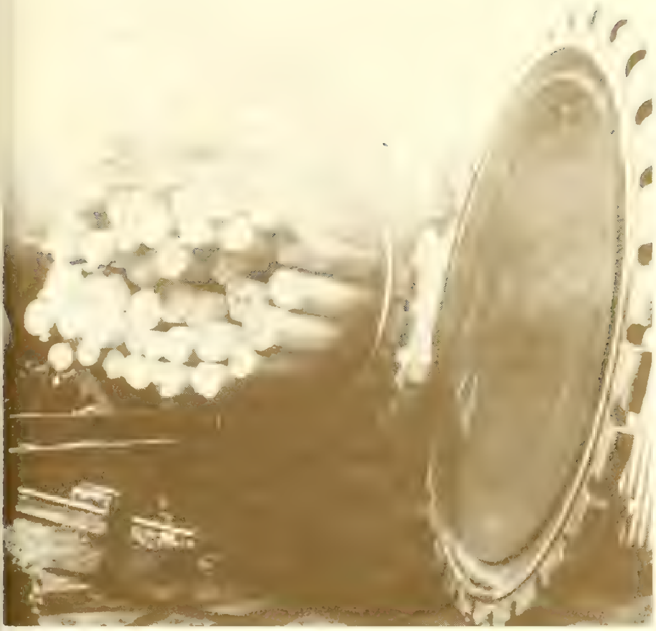

Figure 6.—Fenceposts made from dead lodgepole pines undergo treatment in a pressure cylinder.

Poles

A recent survey of lodgepole pine trees in southeastern Idaho indicated that many of the dead trees were suitable for power poles (Tegethoff and others 1977). Of 217 pole-size trees on 46 plots, 165 were dead; about 38 percent (63) of the dead trees yielded poles that satisfied the ANSI pole standards. The most commonly occurring defect was basal decay; and for many of the dead tree poles this defect had to be eliminated by longbutting.

The preservative treatment of poles made from dead lodgepole pine trees has been reported by Lowery and Host (1979). Thirty poles that were 20, 25, or 30 ft long (6.1, 7.6, or 9.1 m) were butt treated. Six treating schedules, three hot-and-cold bath and three cold soak, were used. The results showed that only one of the poles had less than the minimum required retention of 0.75 inch (1.90 cm), and except for those poles given a 4-hour cold soak, all the poles met the 85 percent sapwood penetration requirement. All the poles treated by the hot-and-cold bath exceeded the preservative retention requirement, AWPA Standard A-5 1969, but none of the poles treated by the cold soak method attained the required retention.

Particle Board

In cooperation with the USDA Forest Service's western Experiment Stations, Washington State University's College of Engineering studied the suitability of using dead lodgepole pine and western white pine trees for particle board manufacture. This investigative effort examined the processing of the wood by the several types of available particle generating equipment; determined the quality, quantity, and uniformity of the resulting particles; and evaluated a variety of composition boards produced from the particles (Maloney and others 1976). A supplementary study compared the economics of producing composition board using deadwood particles as opposed to the conventional green wood furnish (Maloney 1981).

Green and dead standing trees of both species and dead down trees of lodgepole pine were included in the test material. Particles were made by hammermilling, drum and ring flaking, and atmospheric and pressurized attrition milling. Evaluation criteria included energy required to make an ovendry ton of chips, amount of fines, bulk density, and slenderness ratio. The energy requirements in kilowatt-hour per ovendry ton (metric ton) were as follows:

Method	kWh/ton (kWh/t)
Drum flaking	12 (13.2)
Ring flaking	35 (38.6)
Hammermilling	69 (76.1)
Atmospheric attrition milling	101 (111) plus pressurized steam
Pressurized attrition milling	523 (577) plus 450 kWh (496) in processing steam

The amount of fines generated was about the same (4 to 5 percent) for hammermilling and the two types of flaking. For the hammermilled and drum flaked, more fines were created with the dryer material, regardless of species. With the ring flaked, the green material produced the greater amount of fines.

Bulk density is an important factor in determining plant size and equipment. The hammermilled material was the most compact at 10.7 lb/ft^3 (171 kg/m^3). The flakes were intermediate at 6.5 lb/ft^3 (104 kg/m^3) for the ring flakes and 5 lb/ft^3 (80 kg/m^3) for the drum flakes. The two fiber furnishes were about the same, 1 lb/ft^3 (16 kg/m^3). Increasing slenderness tends to enhance bending strength and stiffness but also tends to decrease internal bond strength. The length to thickness or slenderness ratios were 50 for the drum-flaked particles, 22.8 for the ring-flaked particles, and 8.4 for the hammermilled particles. The attrition milled fiber was not measured but probably would be about the same as that of the drum flakes.

Two groups of composition boards were prepared from the various particles. The first group determined the compatibility of the particles with the commonly used urea-formaldehyde and phenol-formaldehyde resin adhesives using these criteria: modulus of rupture, modulus of elasticity, water-soak test, and linear expansion. The second group of boards was typical of those produced commercially for underlayment, furniture core, door core, structural flakeboard, and hardboard.

The major conclusion derived from study of the first group of boards was that the dead classes of white pine and lodgepole pine could be used for various types of

composition board. Of the particles studied, hammer-milled, ring-cut, and atmospheric- and pressure-refined fiber appeared to be best. Structural flakeboards of drum-cut flakes had low internal bond.

Standing dead white pine and lodgepole pine retained those properties important for use in composition board products, even after standing dead for many years. Deterioration such as deep checking, sapstain, and pockets of decay that prevent using these trees for lumber and plywood, also had an adverse effect on their use for particle board.

The typical commercial boards made from the dead class material showed excellent overall properties. All boards had good properties except for excessive linear expansion in lodgepole pine boards and the internal bond in structural flakeboard. All other boards were of superior quality.

An economic comparison study (Maloney 1981) indicated that particle board plants using dead tree stock would require the same major equipment as plants operating conventionally. Using the given condition of starting with roundwood delivered to the plant, particle preparation equipment would be essentially the same. Knives used to prepare the particles from dead trees would probably be subjected to more wear and require more maintenance than those for bolts from green trees. Additional screening capacity might also be needed for the deadwood furnish to segregate the fines. The lower percent moisture content of the dead tree wood would reduce the need for dryer capacity and also reduce the cost of drying. In addition, more waste usable as fuel would be created from the deadwood. The principal conclusion from this study was that comparable composition boards would have similar manufacturing costs no matter which raw material, green or dead trees, was used.

An earlier study (Mueller 1959) indicated that beetle-killed Engelmann spruce from Colorado could also be used in the manufacture of particle board.

Plywood

Deep surface checks and the lower moisture content of long-term dead trees preclude their use for peeling or slicing into veneer. However, trees that have recently died could probably be used in veneer production. The moisture content of wood to be made into veneer is critical and has a distinct effect on cutting (Lutz 1971). In general, wood with a moisture content above fiber saturation but not excessively high is best for cutting into veneer; the higher moisture content makes the wood more pliable. Species with a naturally uniform moisture content of about 50 to 60 percent cut well.

Some of the free water is forced out during cutting. This water apparently acts as a lubricant between the wood, the knife, and the pressure bar and aids the cutting process.

According to Lutz, the driest wood successfully cut into veneer at the Forest Products Laboratory was a flitch of teak with a moisture content of 25 percent. Veneer with pronounced checks was cut from air-dried ponderosa pine planks heated to about 200° F (93° C) in water and at a moisture content of about 15 percent. Satisfactory veneer was cut from similar pine planks after they had been pressure-treated with water to a moisture content of over 100 percent.

Wood Fuel

The principal use of wood worldwide is for fuel, and u until about 1850 wood was the dominant energy source in this country. Today, the constantly increasing price c fossil fuels and other forms of energy is forcing industr and individuals to reevaluate their production and heating needs and to consider alternative energy sources. The wood-using industry has adapted to the changing economic situation by installing wood-fired boilers or cogeneration facilities that use the primary manufacturing waste formerly routed to the burner or landfill. Efficient stoves, readily available from a numbe of manufacturers, are being purchased by many home-owners.

The use of dead timber for fuel has several distinct advantages: the wood is dry, burns readily, and contair very little sulfur; the low moisture content results in a relatively high British thermal unit yield; and the ash residue has value as a soil supplement.

Dead timber is rarely harvested exclusively for fuel. The costs of removing dead trees are essentially the same as for harvesting green timber, and the dead timber's lumber and pulp chip values exceed the fuel value. However, the use of this wood by the individual homeowner is increasing along with the number of woo fired stoves. The Northern Rocky Mountain Region esti mates that in 1980 approximately 257 million board fee (73 759 m^3) of timber was removed from that Region's National Forests by persons desiring fuelwood.

Specifications for firewood are almost personal. All species are used, although western larch and lodgepol pine are often favored. Many people want pieces that wi not require splitting, are small-diameter and 18 to 24 inches (46 to 61 cm) in length. Dry wood, of course, is a basic requirement, and the standing dead trees are usually drier and preferred over the downed trees.

Land managers are using the firewood demand as a means of cleaning up harvested areas and as a way of reducing the fire hazard. The practice of yarding un-utilized material (YUM) brings to the roadside much of the dead timber formerly left on the harvested area, an low-standard roads into dead timber stands allow acce for firewood cutting. Both practices improve timber us and forest esthetics.

House Logs

The market for log homes has increased dramaticall within recent years. Some 200 manufacturers produce about 20,000 log homes in 1979 and probably about 25,000 homes in 1980. Originally used as summer cabi or second homes, log homes are now being used as primary abodes. Several distinct advantages are associated with log homes. They are energy efficient, virtua maintenance free, and fairly durable (Business Week 1979). A well-designed home should last more than 10 years.

Although the majority of log structures use green tree logs, many log home manufacturers of the Rocky Mountain States are committed to using dead trees (fig. 7). Logs made from these trees are usually relatively inexpensive and, because such logs have a lower moisture content, they are lighter in weight than green tree logs. The light weight makes them easier to handle with smaller, less costly equipment, and reduces their shipping cost. Logs with drying checks can be positioned to minimize their effect, and preservative solutions or stains can penetrate and coat all exposed wood surfaces. Finally, structures made of dried logs have less dimensional change and are more stable than structures made from green logs, unless the green logs are air-dried for a rather long time. A typical set of criteria used for selecting house logs, essentially the same for both green and dead timber, are as follows (Peckinpaugh 1978):

1. Free from rot
2. No spiral checks
3. 1/4 inch (0.6 cm) maximum width checks
4. 7 inches (17.8 cm) minimum diameter
5. Minimum length 16 ft (4.9 m)
6. Straight, no crook, and minimum sweep
7. Maximum taper 3 inches in 40 ft (7.6 cm in 12.2 m).

Most dead tree house logs in the Northern Rocky Mountain area are obtained from western white pine and lodgepole pine. However, Engelmann spruce, Douglas-fir, and western larch are also used. Tree length lodgepole pine logs are preferred because the longer lengths permit cutting to the required sizes, and short, usable pieces can often be obtained from trees with spiral grain, sweep, crook, or excessive taper.

Figure 7.—Dead trees used in building log homes provide some advantages green wood logs lack.

Specialty Products

When dead trees are manufactured into lumber, the recovered boards are often of low quality and value. These traits deter the use of more of the dead timber resource. One way of increasing the value of this relatively low quality material is to promote its use for specialty products, such as interior paneling, picture framing, furniture, and decorative moldings. For these uses the differences between dead and green tree wood are accentuated and the uniqueness of the dead tree lumber emphasized. Such is the case for the marketing of white pocket veneer; pecky cypress; knotty pine; wormy chestnut; and gray, weathered barn wood.

Research at the University of Idaho has focused on the use of dead western white pine tree lumber for specialty products (fig. 8) (Howe 1978; Christopherson and Howe 1979). Fourteen white pine logs from dead trees that had been in the log yard for at least 3 years were used in these studies. The logs had a gross Scribner log scale of 4,244 bd.ft. and a net scale of 1,975 bd.ft. The logs were cut into 2-inch and 1-1/4-inch (5.0- and 3.1-cm) thick dimension on a circular sawmill. After drying, the pieces were resawed into paneling 7/16-inch (1.1 cm) thick.

The total volume of lumber recovered from the logs was 3,116 bd.ft.; however, much of this material was subsequently lost during resawing and surfacing. The volume of panel stock obtained was 1,416 bd.ft. (0.41 m^3), with approximately another 1,000 bd.ft. (0.29 m^3) in short salvageable lengths. The value of the paneling and other recoverable pieces was estimated to be considerably above that of the original dimension lumber.

Several mills in the Rocky Mountain area are producing specialty material from ponderosa and lodgepole pine (Howe 1978). The research cited above indicates that western white pine is also suitable for this use.

Figure 8.—High-value specialty products can be made from stained dead tree lumber. (Photo courtesy of University of Idaho.)

Chemical Utilization

Through the years, forest products and wood research have shown that many valuable foods and chemicals can be obtained from wood by means of chemical utilization. Most of these products require extensive treatment and are, therefore, costly to produce under the economic conditions of the early 1980's. However, in the event that chemical utilization becomes a reality, dead tree wood will be a valuable raw material.

SUMMARY

The overmature, unmanaged timber stands of the West contain an abundance of dead trees. Catastrophic losses by insect and disease epidemics, fires, or violent windstorms often result in dead tree concentrations that can become focal points for salvage efforts. But much endemic mortality can only be salvaged as a part of the regular harvesting of green timber. Many of the dead trees contain usable wood and fiber decades after their death. Using the dead timber resource would do much to extend the available timber supplies and have a beneficial effect on subsequent forest management.

The volume of dead timber and its suitability for manufacture is dependent to a large extent on the deterioration prior to harvesting. Studies show that a number of factors can affect the rate of wood breakdown, including species, size of tree, amount of sapwood and heartwood, rate of growth, age of tree, and environment or climate. Deterioration also affects the physical appearance of dead trees, and criteria have been developed to estimate the length of time trees have been dead.

The processing and use of many tree species depend on the inherent physical and mechanical properties as well as the chemical constituents of the wood. Limited studies of the properties and composition of dead tree wood indicate no inherent difference between this wood type and wood from green trees. Dead trees and logs are being used to produce solid wood products such as lumber, house logs, and posts and poles.

Grade-yield studies show that the lumber recovered from dead tree logs is lower in value, quality, and quantity than lumber produced from comparable green tree logs. Also, the longer the time interval between death and utilization, the lower the value of the material recovered. The manufacture of specialty products is one way of enhancing the value of dead tree lumber.

House logs, posts, rails, and poles are other potential uses for dead trees. Dead lodgepole pine trees are preferred by many Rocky Mountain log home manufacturers. Posts and poles made from dead trees can often be treated immediately with a preservative without long air-seasoning, and evidence indicates shorter treating schedules can be used to treat these products.

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The abundant quantity of dead trees in the western National Forests constitutes a resource that may help alleviate present and future timber shortages. A general understanding of the characteristics of this resource and of the wood deterioration process may help provide more complete use. This paper summarizes information obtained from numberous studies of the tree deterioration process and reports results of recent investigations on the uses of dead trees.

KEYWORDS: dead softwood timber, deterioration of dead trees, utilization of dead trees

SURFACE ENVIRONMENT & MINING
SEAM
USDA FOREST SERVICE PROGRAM

WILDLIFE

USER GUIDE
For
Mining and Reclamation

U.S. DEPARTMENT OF AGRICULTURE,
FOREST SERVICE
GENERAL TECHNICAL REPORT INT-126
INTERMOUNTAIN FOREST AND RANGE
EXPERIMENT STATION
OGDEN, UTAH

SUMMARY

The biologist working on a forest where mining developments are occurring must be aware of the relationship between mining and the surface resources, wildlife in particular. This guide covers the major points of concern to the biologist involved in managing wildlife habitat when mineral activity is planned or is occurring. Topics include: the biologist's role in minerals-area management; the legal framework; land-management planning; the phases of mining; guidelines for assessing and evaluating the impacts of mining on wildlife; mitigation measures; and opportunities for wildlife management.

Information includes supporting graphic material, a list of additional sources of information, and a glossary.

ACKNOWLEDGMENTS

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WILDLIFE USER GUIDE FOR MINING AND RECLAMATION

INTERMOUNTAIN FOREST AND RANGE EXPERIMENT STATION

Forest Service
U.S. Department of Agriculture
Ogden, Utah 84401

CONTENTS

Figure 1. Hardrock mining in alpine ecosystem.

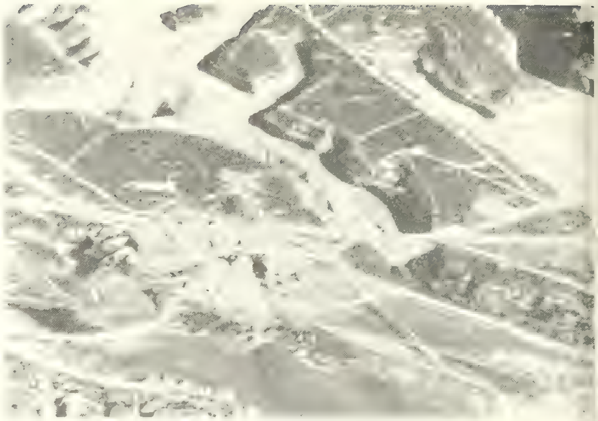

Figure 2. Mining operation.

Figure 4. Oil and gas drilling.

Figure 5. Powerlines are one type of ancillary facility

Figures 1-5. This guide discusses the relationships between mining activities and wildlife.

INTRODUCTION

he Forest Service biologist involved in min- activities needs a working knowledge of eral law and an understanding of the nature the activities necessary to manage wildlife ng mineral projects. Therefore, this guide is nded to describe the relationship between eral activities and wildlife and to aid the ogist in the planning, evaluation, execution, nitoring, and reclamation work associated n mineral projects (fig. 1-5).

HOW TO USE THE GUIDE

he guide is structured so that it can be read ts entirety or used as a reference for address- specific subjects. The first four chapters vide a background and develop a perspective, le chapters 5 through 7 contain information ted to assessment of effects of mineral activ- on wildlife, mitigation measures, and ortunities for managing wildlife that may be ciated with mineral development.

he guide begins with a description of the of the biologist in minerals activities (chap- 1). Chapter 2 contains a review of the laws t pertain to minerals and wildlife and is nded to provide a perspective for examining legal mandates governing evaluation of erals projects.

he significance of land-management planning minerals-area management and wildlife goals objectives is discussed in chapter 3. Informa- in this chapter should be useful when paring land-management plans and when ermining the applicability of approved land- nagement plans to proposed projects.

hapter 4 provides a basic knowledge of eral activities by types of mining. This pter can also be used as a checklist of ected events that might be associated with a posed mineral project.

hapter 5 provides the link between the mineral activity and the expected changes in environmental factors. This chapter contains charts displaying estimates of relative magnitude and duration of the environmental changes from expected events; the estimates are intended to set the framework for assessing mineral projects or land-management planning.

Chapters 6 and 7 list potential changes that could result from mining activities, mitigation measures to consider, and opportunities for managing wildlife. Although chapters 6 and 7 can be used independently for reference, a thorough knowledge of the information in chapters 1 through 5 is recommended for a comprehensive understanding of the information. Provided in the appendices are a glossary of terms used in the publication and references to other wildlife/mineral information.

For the purpose of this guide, the term "wildlife" refers to both terrestrial and aquatic species, because mining can affect both land and water resources. Also, "mining" and "mineral activities" are used in a broad context and apply to locatable, leasable, and salable minerals.

OTHER USER GUIDES

This user guide is one of a series of guides that have been prepared as part of the USDA Forest Service Surface Environment and Mining (SEAM) program. The purpose of these publications is to help those involved in mineral activities more clearly understand their roles. The publications outline some of the major considerations that must be addressed to insure that mineral development is integrated with land-management plans; impacts are mitigated to an acceptable degree; and reclamation meets established performance standards. For those involved in minerals-area management, these guides are seen as a starting point to achieve the common goals of: (1) appropriate consideration

of mineral values in land-management planning; (2) protection of surface resources during mining activities; and (3) reclamation of surface-mined land to productive uses.

User guides on soils, vegetation, hydrology, engineering, and sociology and economics have been published. Each guide focuses on the respective discipline as it relates to managing surface resources affected by mineral activity. This publication is part of the series.

A Forest Service handbook for integrating minerals into the land-management planning process has been written ("Minerals Planning Handbook," FSH 2809.12). A handbook for land managers is also available that discusses the legal and administrative considerations surrounding mineral commodities commonly explored for and developed on National Forest Systems lands ("Land Manager's Handbook on Minerals Management," FSH 2809.11). A handbook on the minerals program (FSH 2809.13) has recently been written and is being printed.

BACKGROUND

Energy and mineral resources are the basic raw materials of United States industry and are highly important to the country's economy and national security. While imports can satisfy a part of the Nation's mineral demands, they tend to make the United States vulnerable to the economic and political decisions of foreign countries. Thus, the conservation and wise use of the mineral deposits within the United States are vital to this country's well-being.

A substantial portion of the domestic mineral supply presently comes from lands managed by the Federal Government. Federal lands are known to contain a majority of the metallic minerals, as well as major resources of coal, oil shale, tar sands, geothermal steam, uranium, and oil and gas.

The Forest Service, as one of the agencies responsible for Federal land management, has an opportunity and challenge to ease U.S. dependency on foreign mineral supplies by facilitating mineral and energy development within the National Forest System (NFS) in concert with other resources values. Considerable untapped mineral and energy resources underlie the 188 million acres of NFS lands. Approximately 6.5 million acres are underlain with coal. About 45 million acres hold potential for oil and gas production, while 300,000 acres have oil shale potential. Significant deposits of other mineral resources, such as cobalt, platinum, group metals, copper, and molybdenum are also found on NFS land.

In many instances, these resources are of low grade, or are in remote areas where development was previously impeded by forbidding terrain and climatic conditions. Today, higher prices, growing demands, and more sophisticated extraction and transportation techniques make development of mineral resources in these areas more attractive than ever. Also, more sophisticated exploration and prospecting techniques dictate that land areas once thought to be void of mineral resources will be explored again for deeper-lying resources. Consequently, industry has increased its prospecting, exploration, and development efforts on previously unexplored NFS lands.

These same Federal lands, however, also contain valuable nonmineral resources, including wildlife, timber, forage, water, scenic landforms, and wilderness. Public holdings of such nonmineral resources are currently among the most significant in the world.

While it is clearly in the national interest to provide for the exploration and production of mineral resources on Federal land, it is also necessary to provide for a sustained high-level output of the various renewable resources. Thus, the demand for mineral development must be balanced with the demand for renewable resources, and the land-management agency's responsibility to manage the environment associated with mineral-related operations.

The Forest Service's primary function in the Federal administration system is to manage renewable surface resources on National Forest System lands. Responsibilities regarding nonrenewable underground resources take shape from that primary surface-management charter. Basically, the Forest Service provides for exploration and extraction of mineral resources, while managing surface resources as provided by law. Even though the Forest Service has no direct responsibility for developing minerals, it has various surface-management authorities that influence the process considerably.

WILDLIFE AND MINERAL ACTIVITY

Because mining projects can affect land uses for long periods of time, individuals responsible for managing wildlife in mineralized areas need to understand the nature and extent of mineral activities that are likely to occur and how that activity could influence wildlife. Generally speaking, working with mineral activities on National Forest System lands is significantly different from working with renewable resources because:

- The Forest Service often does not know in advance where deposits of economically recoverable minerals lie. The technology for locating new mineral deposits is continually being developed and methods for extracting and processing low-grade minerals are improving, making possible the extraction of previously discovered minerals. Improved technology is resulting in mineral development in areas where it was not previously expected.

- In some cases, individuals and industry, not the Forest Service, have the legal right to choose the time and place to explore for some types of mineral resources; in other cases, law gives the public land manager some influence over the time and location of mineral activities.

- Forest Service authorities related to mineral activities are vastly different from its authorities for the management of surface resources. The authorities vary by class of mineral and by the status of the land and mineral estate.

- The Forest Service must respond to proposed project and operating plans within a given time period. This means that the biologist often has to respond with available information because there is not time for new studies or research.

Chapter 1

THE ROLE OF THE BIOLOGIST IN MINERALS-AREA MANAGEMENT

Forest Service biologists are involved with ineral activities on two levels: the broad, gen-al level, which includes legal considerations nd program tasks, and the site-specific level, hich involves actual mining projects. This hapter presents an overview of the biologist's le in minerals-area management on both levels. ven though individual biologists may not parti-pate at both the program and project levels, an nderstanding of both will help them work more fectively as members of the Forest Service am that advises on minerals-area management.

PROGRAM CONSIDERATIONS

The work of the Forest Service is organized to a number of resource and support "pro-ams." A "program" is an administrative frame-ork in which policy and decision-making, udgeting, on-the-ground activities, and report-g functions are accomplished. Wildlife and inerals are two of the Forest Service resource ograms. Others are, for example, recreation d timber.

Wildlife goals and objectives are established rough the interdisciplinary land-management anning process (fig. 6). In this process, all sources are considered, and a comprehensive rface-resource use policy is established by the nd manager for an area. These goals and objec-ves provide guidance for integrating all activ-es on a given land area. The biologist's role d responsibilities in land-management plan-ng are summarized in chapter 3 of this guide.

Other wildlife management activities also take ace at the program level. For instance, an sessment of the workforce needed to respond mineral activities is made. Part of this task is a termination of the number of people and the urs required to make sure that wildlife re-urces are adequately considered when making vironmental assessments and monitoring mineral activities. Because wildlife management requires a knowledge of ecosystems and habitats, some gathering and analyzing of baseline data may take place at the program level.

The development of the program requires coordination with other resource specialists as well as affected Federal and State agencies. Administrative responsibilities among these groups may overlap, so consultation and coordination are often necessary before any firm decisions can be reached on wildlife management practices. This coordination should take place early in the planning process and affected agencies should be kept fully informed. The involved agencies often include the State wildlife agency, the U.S. Fish and Wildlife Service, and the Bureau of Land Management. The biologist can examine the scoping document to identify the needs for coordination.

Another important element of program work is establishing the wildlife budget. The ability to accomplish objectives is directly related to the dollars allocated to the wildlife program. Although budgeting involves numerous steps,

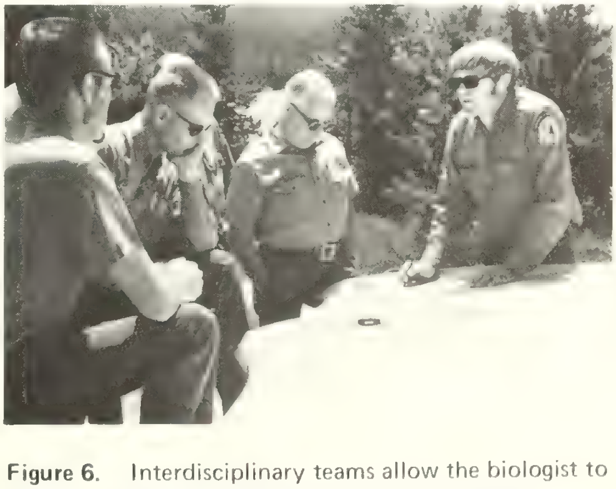

Figure 6. Interdisciplinary teams allow the biologist to participate with other specialists in planning and decision-making.

the following discussion focuses on wildlife budget considerations related to mineral activities.

To develop a wildlife budget that takes mineral activities into account, the biologist relies on the minerals program staff to forecast mineral activities that are likely to occur in the future. These forecasts must identify mineral activities likely to occur over a period of years, because budgets are developed 2-3 years or more prior to the fiscal year in which they are needed. The biologist's job is to use the forecasts to determine the amount of staffing needed to provide the wildlife support to the minerals program. Staffing and funding proposals are useful to the line officer in determining the overal budget.

When mineral activities are expected, th biologist needs to take the following action:

1. Obtain the mineral activity forecasts fron the minerals staff. These should identify th operational phase of each expected project b year.

2. Identify the type of wildlife support wor needed and plan an adequate budget.

3. Identify information needed from othe resource specialists, such as hydrologists o soils scientists.

4. Consider what other circumstances, such a

Figure 7. Fisheries biologists monitor sediment and water quality to determine the effect of mining on fish populations.

ing outside consultants, may arise that might require additional funding.

. Consult with State and other Federal agencies (for example, the U.S. Fish and Wildlife Service) to determine if they will be involved, so that each agency can budget according to its own needs.

. Negotiate with the minerals staff if the support area has not been included or adequately funded.

The budget system provides for including the financing needed for the wildlife support work to be planned and programmed as part of the minerals project. This insures that money will be available to finance the wildlife work when needed.

PROJECT CONSIDERATIONS

Mineral projects can take many forms, ranging from oil and gas exploration to drilling, and from determining the size and shape of an ore body to extracting the ore and reclaiming the soil. When the biologist is asked to participate in the analysis and evaluation of a specific mineral project (or mining-related operation), certain procedures apply. First, the project is examined in light of the environmental, mineral, and wildlife laws that may apply to the situation. Then the proposed project is reviewed in light of the wildlife goals established during land-management planning.

This broad evaluation provides the framework for examining the project on a more detailed level. The proposed project is reviewed to determine: (1) the expected effects on wildlife; (2) how the expected effects will influence both wildlife and its habitat; (3) the extent to which the operator proposes to protect the wildlife resource during mining operations; and (4) other wildlife management practices the biologist believes are necessary.

The concept of reasonableness plays an important role in decision-making processes related to mineral proposals. What is reasonable is determined by considering all alternatives and then choosing the one that best answers the concerns of all parties.

For example, if a company proposes to begin work in 1 year's time, it is not practical for the company to gather information that would take 2-3 years to compile. Many companies are cooperative in regard to gathering baseline data prior to the start of an operation as well as throughout the life of the project. The biologist can help in maintaining this spirit of cooperation through his work with involved agencies and mining companies and by being responsive to time constraints.

Following approval of industry's operating plan, the biologist remains involved during the various phases of mineral activity. For example, the biologist, along with other designated resource specialists, will monitor the project to see if any adjustments are necessary (fig. 7). When considering adjustments and evaluating alternatives, the biologist identifies both onsite and offsite mitigation measures. This provides an opportunity to be innovative in stimulating new concepts in terms of treatments that are available through advancing technology.

Another aspect of the biologist's role is to identify needed research projects that often are identified during project evaluation. Research proposals are developed and submitted through appropriate Forest Service channels.

Note: a brief summary outline of the phases of mineral exploration and development activities is presented in table 1. A more in-depth discussion of these phases is found in chapter 4. The biologist's role within these activities is shown at the bottom of the table; it is also summarized in table 2, along with the roles of other Forest Service specialists.

Table 1.—*Phases of mineral exploration and development activities*[1]

Prospecting	Exploration	Feasibility studies/operating plan
A. Administrative Action No administrative action required, however, some evidence of mineralization or a hunch	**A. Administrative Action** Permit/Lease Notice of intent from miner (for certain commodities, may also serve as operating plan if there is minimal surface disturbance) Exploration license EA may be necessary See Land Manager's Handbook on Minerals Management for variation within commodities	**A. Administrative Action** Submission of necessary permits (EA, EIS, etc.) and operating plan—see Land Manager's Handbook on Mineral Management for variation within commodities
B. Activities Literature search Geological inference Evaluation of existing data Research on rights to land/minerals	**B. Activities** More intensive literature search Access road construction Onsite testing and evaluation of data—geological, geochemical, geophysical, drilling, sampling, shaft sinking Seismic activity Acquiring land/mineral rights Rehabilitation of exploration impacts Environmental and socioeconomic studies	**B. Activities** Feasibility studies Grade and size of deposit Cost of mining and rehabilitation Market Fiscal Technical studies—mine design Environmental and socioeconomic studi (if not done during exploration) Decision to proceed with development Preparation of operating plan including rehabilitation program and end use Ordering of equipment
C. Environmental Impacts Minimal, if any	**C. Environmental Impacts** Roads Drill holes Drill pads Dozer holes Exploration camps	**C. Environmental Impacts** Generally none at this stage
D. Tasks for the Biologist Complete wildlife action plan for mineral deposit areas Plan for: coordination with other State/Federal wildlife agenices' budget needs, collection of necessary baseline data, monitoring requirements, analysis of fish and wildlife values, and priorities	**D. Tasks for the Biologist** Review plans that affect the wildlife resource, determine need for more specific project level information, assist in study design and data collection Incorporate other State and Federal wildlife agency input, consider need for cooperative agreements or memorandums of understanding Review plans and recommend procedures to protect wildlife and to reclaim habitat affected by exploration	**D. Tasks for the Biologist** Review adequacy of operating plan for: wildlife considerations (harassment, human interference, habitat disturbanc and loss, pollution, direct mortality, opportunities) Provide expertise in environmental analysis process Consider both onsite and offsite effects Assist in identifying State-Federal responsibilities for monitoring and evaluation Develop management options

[1]The various phases have considerable overlap. The material provided for each phase is illustrative, not complete, and considerabl variation is found by mineral commodity. The existence of a forest plan is assumed. Tasks (D) are primarily input from a land management agency's biologist. For purposes of discussion, the terms reclamation and rehabilitation are used interchangeably, anc mining includes oil and gas activities.

Development[2]	Production/reclamation	Postmining
A. Administrative Action Approval of necessary operating plan	**A. Administrative Action** No administrative action required. Production overlaps with development and reclamation overlaps with production; reclamation of previously mined areas occurs concurrently with new production as stipulated in operating plan Any changes in operating plan	**A. Administrative Action** Release of reclamation bond
B. Activities Securing of financing More extensive testing and definition of the mineral Construction of transportation routes and utilities Construction of mine and processing plant (facilities, water supply, etc.) Construction of waste deposits Continued evaluation of data Change mining plan if necessary	**B. Activities** Extraction of mineral Processing of mineral Depositing wastes Operation of transportation systems Rehabilitation Monitoring for any changes in biological and physical environment Amend mining and rehabilitation plan if necessary	**B. Activities** Surface owner manages land after bond release Monitoring for any changes in biological and physical environment Management and maintenance for end-use objective
C. Environmental Impacts Mine Processing plant Waste dumps Transportation and access routes Utilities Increased population resulting from construction	**C. Environmental Impacts** Impacts directly related to operational aspects of production impacts are strongly affected by commodity and type of operation	**C. Environmental Impacts** Directly related to management and maintenance activities
D. Tasks for the Biologist Monitor wildlife impacts and activities for conformance to operating plan Advise on plan revisions when necessary, inform and involve mining companies on current studies and monitoring	**D. Tasks for the Biologist** Monitor wildlife impacts and activities for conformance to operating plan Advise on plan revisions when necessary, inform and involve mining companies on current studies and monitoring Provide ad hoc technical assistance	**D. Tasks for the Biologist** Monitor any continued impacts on wildlife Manage habitat for end-use objective

[2]Development is herein defined as the phase which begins after the right to mine has been established.

Table 2.—*Roles of Forest Service specialists in mineral activities*

	Prospecting	Exploration	Feasibility studies/operating plan
Biologist	Complete wildlife action plan for mineral deposit areas Plan for: coordination with other State/Federal wildlife agencies' budget needs, collection of necessary baseline data, monitoring requirements, analysis of fish and wildlife values, and priorities	Review plans that affect the wildlife resource, determine need for more specific project level information, assist in study design and data collection Incorporate other State and Federal wildlife agency input, consider need for cooperative agreements or memorandums of understanding Review plans and recommend procedures to protect wildlife and to reclaim habitat affected by exploration	Review adequacy of operating plan for wildlife considerations (harassment, human interference, habitat disturbance and loss, pollution, direct mortality, opportunities) Provide expertise in environmental analysis process Consider both onsite and offsite effects Assist in identifying State-Federal responsibilities for monitoring and evaluation Develop management options
Vegetation specialist	None at this point	Review of plans to reclaim land impacted by exploration Review and assist in vegetation aspects of environmental studies	Review adequacy of operating plan for: Reclamation program— species selection plant materials site preparation planting methods cultural treatments Monitoring/retreatment program for vegetation Vegetation aspects of end use
Soils scientist	None at this point	Review of plans to reclaim land impacted by exploration Review and assist in soils aspects of environmental studies Review soils inventory progress in the mineralized areas; if needed recommend timely completion or upgrading	Review adequacy of operating plan for: Reclamation program— soils surveys storage area selection materials handling plans spoils analysis plan spoils treatments spoils surfacing and erosion control Monitoring/retreatment program for soils Soils aspects of end use
Hydrologist	Establish baseline water-quality monitoring as needed according to plan	Review of plans to reclaim land impacted by exploration Review and assist in hydrologic aspects of environmental studies	Review adequacy of operating plan for: Hydrologic considerations— surface water subsurface water snow management roads impoundments mine drainage Hydrologic aspects of end use
Engineer	None at this point	Review of plans to reclaim land impacted by exploration Review and assist in engineering aspects of environmental studies	Review adequacy of operating plan for: Engineering considerations— air pollution transportation facilities surface-mine facilities mine-waste disposal embankments tailings dams and impoundments subsidence Engineering aspects of end use
Economist	Monitor factors which affect supply and demand for minerals Make forecasts of supply and demand Predict probability	Analyze costs and benefits of alternative exploration methods Participate with the sociologist in identification of existing and emerging issues	Provide expertise in environmental analysis process: issue identification decision criteria cost/benefit analysis of alternatives tradeoff and opportunity-cost evaluations Analyze effects of development on: demand for surface resources human behavioral patterns community economics
Sociologist	Identify the basic social/cultural descriptors of the affected communities Note current trends	Assist in structuring public involvement plan for appropriate: issue identification issue analysis mitigation action Identify critical trigger points from a social perspective	Provide expertise in environmental analysis process: decision criteria issue identification Analyze effects of development on the cultural and political community Consider effects of alternative plans on social well-being
Minerals program staff	Update mineral inventory/mineral activity forecasts as information becomes available May be assigned tasks of (1) resolving conflicts, (2) coordinating required Forest Service staff work, or (3) liaison with other Government agency activities during this phase Review prospecting operating plan/permit application, if required and prepare EA	Update LMP data base with new mineral information as it becomes available Review exploratory operating plan and help prepare EA, if required Consult with land manager on regulatory requirements and setting reclamation bond Serve as liaison between industry and Forest Service Serve as contact point with other Government agencies Judge reasonableness of mining activity; possible participation in any contest actions or resulting litigation, appeals, or congressionals	May serve as ID team leader in reviewing adequacy of operating plan: Coordinate activities of ID team/other Government agencies Prepare EA or EIS Interpret regulations Assist in public involvement activities Negotiate among interested parties Monitor conformance with approved operating plan

Development	Production/reclamation	Postmining
Monitor wildlife impacts and activities for conformance to operating plan Advise on plan revisions when necessary, inform and involve mining companies on current studies and monitoring	Monitor wildlife impacts and activities for conformance to operating plan Advise on plan revisions when necessary, inform and involve mining companies on current studies and monitoring Provide ad hoc technical assistance	Monitor any continued impacts on wildlife Manage habitat for end-use objectives
Monitor vegetation impacts and activities for conformance to operating plan Advise on plan revisions when necessary	Monitor vegetation impacts and activities for conformance to operating plan Advise on plan revisions when necessary Advise from a vegetation standpoint on release of reclamation bond	Monitor any continued impacts on vegetation Manage vegetation for end-use objectives
Monitor impacts on soils Monitor soils-related activities for conformance to operating plan Advise on plan revisions when necessary	Monitor soils impacts and activities for conformance to operating plan Advise on plan revisions when necessary Advise from a soils standpoint on release of reclamation bond	Monitor any continued impacts on soils Manage soils for end-use objectives
Monitor impacts on hydrology	Monitor impacts on hydrology and hydrologic aspects of rehabilitation program Have hydrologic input into release of reclamation bond	Monitor any continued impacts on hydrology Manage hydrology for end-use objectives
Monitor engineering-related activities for conformance to operating plan Advise on plan revisions when necessary	Advise from an engineering standpoint on release of reclamation bond	Monitor any continued impacts from engineered structures Manage structures for end-use objectives
Record costs Monitor economic changes	Record costs Monitor economic changes	Monitor to determine accuracy of predictions for future use
Monitor Record changes Identify areas of individual or group stress relating to mineral activity and make recommendations to mitigate effects	Monitor Record changes	Monitor and record critical changes to establish new baseline situation
Maintain liaison with appropriate industry/Government officials Respond to operating plan amendments Monitor for compliance with operating plan	Monitor conformance with approved plan: Liaison with appropriate Government agencies Monitor compliance with operating plan Negotiate among interested parties Monitor conformance with approved reclamation plan	Maintain liaison Inspect site regarding bond release

Chapter 2

LEGAL FOUNDATIONS

Working in minerals-area management re-
ɹires a basic understanding of the Federal and tate laws and regulations that govern mineral :tivities and the wildlife resource. Several broad ıtegories of laws and regulations apply to ıining and wildlife on National Forest System nds: (1) general laws; (2) mineral laws and the ɔncept of split mineral and surface estates; and }) wildlife laws.

The discussion of laws and regulations pro- ded in this chapter is an overview of some of ıe major regulations that apply to mineral :tivity and wildlife management on National orest System lands. The Forest Service has dif- ꞉rent authorities related to mineral resources ıd mining activities than it has for renewable ırface resources. Mineral law governs the nature ıd extent of Forest Service authority relative ɔ mineral operations. Authorities vary depend- ıg on the class of mineral (locatable, leasable, ıd salable), the status of the land (public do- ıain or acquired), and the status of the mineral ;tate. Depending on the circumstances, Forest ervice authority can range from total discre- on, recommendation, consent, or the deter- ıination of mitigation requirements for the rotection of surface resources.

Other agencies have significant authorities ꞉lative to minerals management on National orest System lands. Some of the jurisdictions ·e spelled out in mining laws and regulations, 'hile others have developed out of memoran- ums of understanding negotiated between dif- ꞉rent agencies.

This combination of laws, regulations, legal ɔncepts, and memorandums of understanding ɔmetimes creates complex situations. Where otential conflicts between mineral and wildlife ıws exist, the biologist should consult with ıineral law experts to clarify particular situa- ons. The discussion of laws and regulations rovided in this chapter is an overview of some f the major requirements that apply to mineral activity and wildlife management on National Forest System lands.

GENERAL LAWS

A brief summary of some of the major enabling legislation and environmental laws follows:

- **The Organic Administration Act of 1897.**[1] Although this act is not primarily concerned with mineral developments on National Forests, it provides for the continued right to conduct mining activities if the activities comply with the rules and regulations covering such National Forests. It also states that miners and prospectors have the right of ingress and egress into National Forests for all proper and lawful purposes, including that of prospecting, locating, and developing the mineral resources on the forests.
- **Multiple-Use Sustained Yield Act of 1960.**[2] This act authorizes and directs the Secretary of Agriculture to "develop and administer the renewable surface resources of the National Forests for multiple use and sustained yield of the several products and services obtained therefrom....Nothing herein shall be construed so as to affect the use or administration of the mineral resources of National Forest lands or to affect the use or administration of Federal lands not within National Forests."
- **The Wilderness Act of 1964.**[3] This act provides that from September 3, 1964 until mid-

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[1] Act of June 4, 1897. (30 Stat. 34, as amended; 16 U.S.C. 473-478, 479-482, 551).

[2] Act of June 12, 1960. (74 Stat. 215, as amended; 16 U.S.C. 528-531).

[3] Act of September 3, 1964. (78 Stat. 890; 16 U.S.C. 1131-1136).

night December 31, 1983, lands classified as wilderness shall remain open to the action of the United States mining laws and all laws pertaining to mineral leasing. However, effective January 1, 1984, the wilderness areas are withdrawn from all forms of appropriation under the mining and mineral leasing laws. Patents (legal titles) issued for mining claims prior to 1984 will convey only mineral rights; surface rights will be reserved to the United States.

• **The National Environmental Policy Act of 1969 (NEPA).**[4] This act requires all Federal agencies to use a systematic, interdisciplinary approach to insure the integrated use of natural and social sciences in planning and decision-making. It also directs that a detailed environmental analysis of proposed Federal actions be completed to determine the effects of those actions on the environment. Mineral activities, with the exception of mineral patent applications, are subject to this law. Wildlife and fish values must be considered during the interdisciplinary analysis, including any long-term, offsite, or cumulative effects on the wildlife resource.

• **The Federal Water Pollution Control Act of 1972.**[5] This act concerns the restoration and maintenance of the chemical, physical, and biological integrity of the Nation's waters. It specifies that water quality must be sufficient for use by fish and wildlife, and requires the Environmental Protection Agency to develop regulations establishing Federal standards for control of pollutant discharge. Therefore, any mineral activities that involve water must be evaluated in relation to chemical and biological standards for fish and wildlife habitats.

• **The Clean Water Act, as amended in 1972.**[6] This act specifies the development of the best management practices (BMP) for water resources. With respect to mining activities, Federal agen-cies cooperate with the States to control minin and construction sources of water pollution.

State water quality laws and regulations usual-ly provide the enforcement authority for wat quality regulations; the implementation of th Clean Water Act is accomplished through co-operative agreements between the States and th Federal government. In mineral activities, th Forest Service biologist should examine th cooperative agreements with the States to ide-tify the applicable BMP. The BMP's are the ma-agement guidelines for aquatic and ripari habitats in relation to water quality.

• **The National Forest Management Act 1976 (NFMA).**[7] NFMA states that consider-tions of wildlife and fish resources must be i-cluded in the interdisciplinary land-manageme planning effort to identify land suitabilities f resource management, including minerals ma-agement. This act directs the Forest Service provide for a diversity of plant and animal com-munities. The effects of mineral activities o wildlife habitat diversity are an important el-ment in project evaluations. Monitoring th effects of minerals activities on wildlife and fi habitats is also a Forest Service responsibility.

In addition, NFMA states that special manag-ment attention is required in riparian habitat land areas adjacent to bodies of water. The a prohibits management practices causing det-mental changes in water temperature or chem-ical composition, water blockages, and deposi of sediment within those areas if such occu-rences seriously or adversely affect water con-tion or fish habitat.

LAWS AND REGULATIONS GOVERNING MINERALS AND MINING

• **The General Mining Law of 1872.**[8] Th law is still in force today. The 1872 law declar "all valuable mineral deposits in lands belongi

[4]U.S. Laws, Statutes, etc. Public Law 91-190 (S. 1075), Jan. 1, 1970. National Environmental Policy Act of 1969. An act to establish a national policy for the environment, to provide for the establishment of a Council on Environmental Quality, and for other purposes. In its United States Statutes at large. 1969. Vol. 83, pp. 852-856. U.S. Gov. Print. Off., Washington, D.C. 1970. (42 U.S.C. 4321, 433-4335, 4341-4347).

[5]P.L. 92-500 (86 Stat. 816; 33 U.S.C. 1251).

[6]P.L. 95-217 (91 Stat. 1566; 33 U.S.C. 446 et seq.).

[7]U.S. Laws, Statutes, etc. Public Law 94-588 (1075), Oct. 22, 1976. National Forest Management A of 1976. In United States code congressional and admi istrative news. 94th Congr. 2d sess., 1976. Vol. p. 2949-2963. West Publ. Co., St. Paul, Minn. (1976).

[8]Act of May 10, 1872. (17 Stat. 91).

to the United States...to be free and open to exploration and purchase." It authorized placer and lode mining claims to be located by a procedure that is largely unchanged to this day. The act also requires that not less than $100 worth of work be performed on each claim per year.

The 1872 Mining Law permits an individual to, upon discovery of a valuable mineral deposit, locate a claim. In order to keep the claim in good standing the claimant must perform $100 worth of work a year. An individual may locate as many claims as desired as long as the land is not withdrawn and the person abides by the provisions of the mining law. In the case of placer claims, the individual is limited to a 20-acre claim. However, a group of individuals may join together and locate an association placer claim, which encompasses more than 20 acres. As many as eight individuals may participate in the location of a single association placer claim, which encompasses 160 acres (20 acres per participant). If the claim remains unpatented, the claimant possesses the right to extract and remove the locatable minerals, but he cannot sell the mineral material from the claim nor have full title to the property.

Later modification of the 1872 Act excluded certain minerals. Today, the 1872 Act concerns hardrock minerals (gold, silver, zinc, etc.) on public domain lands.

• **The Mineral Leasing Act of February 25, 1920.**[9] The Mineral Leasing Act of 1920 provided that deposits of coal, phosphate, oil, oil shale, gas, and sodium could be acquired through a leasing system. This law specifies, among other things, royalty rates, rental rates, lease size, and terms required for each kind of leasable mineral. The law also provides for issuance of prospecting permits prior to lease issuance and competitive bidding for certain deposits.

Generally, with respect to National Forest System lands that were removed from the public domain to create the National Forest System, the Bureau of Land Management, under an interdepartmental agreement, requests Forest Service *recommendations* on leasing decisions and on stipulations and conditions to attach to leases. Provisions are included that allow the incorporation of lease stipulations to protect surface resource values.

• **The Mineral Leasing Act for Acquired Lands of August 7, 1947.**[10] This act authorizes mineral leasing on acquired lands—lands the Federal Government bought from private landowners for a specific purpose. Leases on acquired lands may only be issued with the consent of the Secretary of Agriculture and are subject to conditions that insure the lands are used for the purpose for which they were acquired. Leasable minerals covered by this act include coal, phosphate, oil and gas, oil shale, sodium, potassium, and sulfur. In addition, minerals covered by the 1872 Mining Law, as amended, on public domain lands are subject to the 1947 Act on acquired land. This law is administered through the Bureau of Land Management.

• **The Materials Act of 1947.**[11] This act authorizes disposal of salable materials including, but not limited to, sand, stone, gravel, and common clay on public lands through a sales system. If the appraised value of the material exceeds $1,000, it must be disposed by competitive bidding. The law also provides for free use of material by government agencies, municipalities or nonprofit organizations, if the material is not to be used for commercial purposes. Disposal of these minerals is handled through the agency administering the land.

• **The Multiple Use Surface Act of 1955.**[12] This act provides that the Forest Service has the right to manage and dispose of the vegetative surface resources and to manage other surface resources, including wildlife habitat, on valid mining claims. Under this act, common varieties of sand, gravel, cinders, pumice, pumicite, and clay were removed from the category of locatable minerals and placed under the Materials Act of 1947.

Federal regulations 36 CFR 228 direct that exploration and mining activities be conducted so as to minimize adverse environmental impacts. A Notice of Intent to Operate must be

[9] The Act of February 25, 1920; 41 Stat. 437.

[10] Act of August 7, 1947; 61 Stat. 913.

[11] Act of July 31, 1947; 61 Stat. 681.

[12] Act of July 23, 1955; 69 Stat. 367.

filed with the respective District Ranger prior to conducting an activity that might disturb the surface resources. The operator is required to reclaim all lands affected by the mining operation, including wildlife habitat.

• **The Federal Coal Leasing Amendments Act of 1976.**[13] The act gives the Forest Service consent authority for coal leasing and operating plan approval on National Forest System lands. The act states that no coal leases will be issued unless the lands have been included in a comprehensive land-use plan and the development of the coal resource is compatible with the established plan.

• **The Federal Land Policy and Management Act of 1976 (FLPMA).**[14] One provision of this act requires mining claimants to record their location notices and their annual assessment work with the Bureau of Land Management in addition to the local county recorder as required by State law and regulation. These records, for the first time, provide an up-to-date, accurate listing of mining claims data. This act also contains mineral withdrawal provisions.

CONCEPTS RELATED TO MINERAL LAW

Familiarity with the precise wording and meaning of mineral law is one aspect of the legal foundations of minerals-area management. The role of the Forest Service in mineral activities on National Forest System lands depends upon the status of the land and mineral rights. Hence, Forest Service authority over mineral development is not all-inclusive, nor is it identical from one case to another. To understand the role of the Forest Service in minerals management, the biologist should have a working knowledge of the following concepts that govern Forest Service actions:

• **Mineral estates.** Because of the complex ownership situations that exist in regard to minerals and shared ownership or overlapping authorities, considerable coordination among government agencies is necessary if the minerals management program is to be effective. For example, various Federal and State agencies may have jurisdiction over one or more segments of the development. Hence, involved agencies must be included in certain phases of the planning and/or decision-making process.

Split ownership of surface and mineral estates occurs when one party has jurisdiction over the mineral estate and another has jurisdiction over the surface rights. The law allows mineral and surface rights to be bought and sold separately. Therefore, different parties may each have rights to the same piece of property.

For example, the Federal Government bought a great deal of land, especially in the Eastern States, without obtaining ownership of the minerals under the surface. Rights to some of these minerals remain "outstanding" or "reserved" to private owners, and these individuals may remove the minerals at any time, subject to the surface management requirements of Federal and State laws.

Reserved rights mean that the party conveying land to the United States retains ownership of all or part of the mineral rights. The exercise of these rights is conditioned by the Secretary of Agriculture's "Rules and Regulations," which are sometimes attached to and made a part of the deed, and by State laws. This provision gives the Federal Government some surface control authority.

In contrast, outstanding rights mean that all or part of the mineral rights are held by a third party—*not* the party conveying the land to the United States. No Secretary's Rules and Regulations may be applied, because the third party is not an active participant in the conveyance of land to the Government, and duties and restrictions cannot be imposed without this party's consent. The exercise of the mineral rights is conditioned by the specific language conveying (or reserving) the mineral rights and by legal interpretations. The net result of outstanding mineral rights is that possibilities for surface control authority vary from zero to comprehensive depending upon the type of title conveyance, legal interpretation, and existing State laws (see table 3).

• **Land acquisition considerations.** The manner in which the land was acquired affects Forest Service authorities. Lands are classified as either public domain or acquired, and the dis-

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[13] Act of August 4, 1976; (90 Stat. 1083; 30 U.S.C. 181-287).

[14] Act of October 21, 1976; (43 U.S.C. 1701 (note)).

tinctions between the two classifications determine Forest Service authority and responsibility regarding mineral development.

Generally, public domain lands, unless specifically withdrawn, are open to mineral exploration and development under the U.S. Mining Law of 1872, as amended. On the other hand, acquired lands are open to leasing under the 1947 Acquired Lands Act.

The Forest Service generally has greater authority over minerals on acquired lands than on public domain lands, because the authority to grant consent for development of certain resources exists. Consent can be withheld, based on valid reasons, and if consent is given, stipulations can be attached to the license, permit, or lease issued by the Department of the Interior.

Based on the 1872 Mining Law, public domain lands, unless withdrawn from mineral entry, are open for mineral exploration and development. If a mineral is classified as leasable (see below), the Forest Service can recommend or require that stipulations be attached to the lease.

• **Disposal of Federally owned minerals.** All minerals owned by the United States that are available for exploration and development are disposed under one of three categories—locatable minerals, leasable minerals, and salable minerals.

Locatable minerals are mineral deposits on "open" public domain lands that were originally subject to disposal under the 1872 Mining Law. Those minerals that were not excepted in later legislation remain subject to this law. Gold, silver, and tin are among minerals classified as locatables.

For locatable minerals, specific regulations outlined in the Secretary of Agriculture's regu-

Table 3.—*Mineral authority matrix*[1]

Circumstance	Responsible Agency		
	USDA Forest Service	Bureau of Land Management	U.S. Geological Survey
Locatable minerals			
1. Surface management (as directed by 36 CFR 228) includes notice of intent, operating plan on public domain lands	X		
2. Mining claim recordation and patent compliance		X	
3. On acquired lands	X	X	
Leasable minerals			
1. Lease issuance on both acquired and public domain lands		X	
2. Recommendations and evaluation of lease applications on public domain lands	X		
3. Consent authority for coal on public domain lands	X		
4. Consent authority on acquired lands	X		
5. Processing of prospecting permits	X		
6. Evaluation of operating plans	X		X
7. Mining operations			X
8. Access on NFS lands	X		
Salable minerals			
All activities	X		

[1]For more detailed information see FSH 2809.11, "Land Manager's Handbook on Minerals Management."

Table 4.—*Federal laws and regulations governing minerals and wildli*

Requirements, Responsibilities, and Procedures	Endangered Species Act	Bald Eagle Protection Act	Migratory Bird Treaty Act	NEPA	NFMA	Water Pollution Control Act	Clean Water Act	Fish and Wildlife Coordination Act	Executive Order 11988*	Executive Order 11990*	Mining Law of 1872
U.S. Fish and Wildlife Service responsibilities	X	X	X								
Environmental analysis requirements				X							
Planning requirements					X						
Water quality and wetlands requirements						X	X	X	X	X	
Locatable mineral procedures											X
Salable mineral procedures											
Leasable mineral procedures											
• Other than commodities listed below											
• Oil and gas											
• Coal											
• Geothermal											

*Not discussed in text.

lations (36 CFR 228 [formerly 36 CFR 252])[15] must be adhered to when mining activity is proposed on National Forest System land. The regulations provide that:

1. A "notice of intention to operate" must be filed with the local Forest Service office for proposed prospecting or mining operations covered under the 1872 Mining Law when the activit might cause a disturbance to surface resourc on National Forest System lands. If the autho ized Forest Service officer determines that th operations will cause a significant disturbance t the environment, the operator must submit proposed plan of operations.

2. All operations must be conducted, insof as possible, to minimize adverse environment impacts on the National Forests.

3. The plan of operations must detail th steps the operator will take for feasible rehabi

[15] National Forest Mineral Resources—USDA rules on prospecting, exploration, and mining procedures: effective 9-1-74 (36 CFR 228).

they relate to public agencies' actions

Material Minerals Act (.4) (36CFR251.4)	Mineral Leasing Act (30CFR231) (43CFR23)	Mineral Leasing Act (30CFR221) (43CFR3100)	Federal Coal Leasing Amendments Act (30CFR211) (43CFR3225)	Surface Mining Control and Reclamation Act* (30CFR700)	Geothermal Steam Act* (30CFR3200) (43CFR270)
X					
	X				
		X			
			X	X	
					X

ation when the prospecting or mining is ompleted.

4. The operator may be required to furnish a ond commensurate with the expected costs of habilitation.

5. The plan of operations must be approved / the authorized Forest Service officer before ıy operations are conducted.

Leasable minerals have been excepted from e 1872 Mining Law by:

1. Specifying certain minerals by name (for ample, geothermal resources).

2. Providing a leasing system for minerals on land with acquired status.

Salable minerals are available for disposal under a separate system, primarily because of their widespread occurrence. These minerals are classified by statute as "common variety" minerals. Examples are gravel and stone. Minerals of the same type that have some property giving them distinct and special value are considered "uncommon varieties" and are disposed of under the General Mining Law of 1872 as amended. The character of the deposit determines whether the mineral is classified as a locatable or a salable.

WILDLIFE LAW

Wildlife management on public lands administered by the Forest Service is complicated by the fact that many agency responsibilities and authorities are involved (see table 4). Generally the State, through the State fish and wildlife agency, has the responsibility for management of wildlife populations. The Forest Service, as the land-management agency, is responsible for the management of wildlife habitat on lands it administers. A third agency, the U.S. Fish and Wildlife Service, is also involved because of responsibilities for enforcing Federal legislation involving threatened and endangered species and migratory species. Wildlife management on Forest Service-administered lands is therefore often a joint effort among these three agencies, and its success is contingent upon interagency coordination.

The basic authority for the State's management of the wildlife rests in the U.S. Constitution and the subsequent State ownership doctrine. State responsibilities include: (1) setting and administering hunting and fishing regulations; (2) enforcing State wildlife laws and providing regulations; (3) basic inventory and research; and (4) providing expertise on wildlife population management. Close coordination with the State agency biologist is an important step in the analysis and evaluation regarding mineral activities.

The U.S. Fish and Wildlife Service is the lead agency administering the Endangered Species Act. All Federal actions that may affect a Federally listed threatened or endangered species

must be reviewed by the U.S. Fish and Wildlife Service in a formal consultation process. The U.S. Fish and Wildlife Service also has responsibilities stemming from the Bald Eagle Protection Act of 1940, which involves protection of bald and golden eagles. The Fish and Wildlife Service also has responsibilities dealing with migratory species that cross state lines.

The following are several important wildlife laws:

• **The Endangered Species Act of 1973 (Amended 78, 79).**[16] Administered by the U.S. Fish and Wildlife Service, this act directs that actions authorized, funded, or carried out by a Federal agency must not jeopardize the continued existence of a Federally listed threatened or endangered species (fig. 8). A formal consultation process is established in which the Fish and Wildlife Service is consulted on Federal actions that may affect a threatened or endangered species. The Forest Service has the responsibility for evaluating proposed mineral activities on lands it administers to determine if such activities affect a Federally listed species. Any State-listed species will be handled in the same manner, except that formal consultation with the U.S. Fish and Wildlife Service is not required.

• **The Bald Eagle Protection Act of 1940.**[17] This act gives Federal protection to bald and golden eagles; the Fish and Wildlife Service is also responsible for the act's enforcement. Mineral activities that directly cause the abandonment or failure of a golden or bald eagle

[16] P.L. 93-205 (16 U.S.C. 1531 et seq.).

[17] P.L. 92-535 (1, 86 Stat. 1064; 16 U.S.C. 668-668d)

Figure 8. Federal laws provide for the protection of threatened and endangered species, such as the bald eagle.

nest site may be in violation of this act.

• **Migratory Bird Treaty Act of 1918.**[18] This act gives Federal protection to migratory birds and is enforced by the U.S. Fish and Wildlife Service. The Forest Service has the responsibility for evaluating proposed mineral activities on lands it administers to determine if such activities affect migratory birds.

• **The Anadromous Fish Conservation Act of 1965.**[19] The purpose of this act is "...to conserve, develop, and enhance the anadromous fishery resources of the nation that are subject to depletion from water-resource developments and other causes, such as mining. Water quality must also be maintained consistent with U.S. conservation commitments by international agreements...for the purpose of conserving, developing, and enhancing fish in the... Columbia River basin that ascend the streams to spawn...." The Secretary of the Interior makes recommendations to the Secretary of Health and Human Services concerning the elimination or reduction of polluting substances detrimental to fish and wildlife in interstate or navigable waters or their tributaries.

[18] Act of July 3, 1918 (40 Stat. 755).

[19] Act of October 30, 1965, P.L. 89-304 (79 Stat. 125 16 U.S.C. 757a-757f).

Chapter 3

WILDLIFE OBJECTIVES IN LAND-MANAGEMENT PLANNING

When the biologist is asked to evaluate a mining project, he needs a framework or perspective in which to do the evaluation. The laws, regulations, and concepts introduced in chapter 2 provide the legal framework; the land-management plan, or forest plan, also adds to the perspective.

The forest plan is important to the analysis of a specific mineral project because the plan establishes the goals, objectives, and standards for managing the National Forest. Although it is not site specific, the objectives established for the overall area are useful in the review of proposed activities. This chapter discusses the general land-management planning process and the manner in which minerals and wildlife are integrated into the process.

LAND-MANAGEMENT PLANNING

The forest plan is a land-management plan that outlines the most desired uses for specific land areas, keeping in mind that a primary role of the Forest Service is to manage surface resources. The procedures for developing this plan are listed in rules and regulations in the Federal Register (vol. 44, no. 181, 9/17/79). These rules and regulations detail the requirements of the National Forest Management Act of 1976 (NFMA), which specifies that all resources—such as wildlife, minerals, timber, and recreation—must be addressed in the plan.

A key element in the planning approach is the interdisciplinary (ID) team, a requirement of the NFMA. The act requires all pertinent specialists to work as a team in developing forest plans. NFMA specifically requires that ID teams, consisting of personnel who collectively represent diverse areas of resource knowledge, consider, analyze, and solve resource problems in an integrated manner. This is in contrast to a functional or multidisciplinary approach in which resource problems are separated, analyzed, and solved along disciplinary lines.

When the ID team is formed for the purpose of developing a land-management plan, members are directed by NFMA regulations to carry out 10 formal planning actions (fig. 9). Although NFMA regulations state that all resource values present on an area must be considered in the planning process, the remainder of this chapter discusses the coordination of two resources—wildlife and minerals.

MINERAL CONSIDERATIONS IN LAND-MANAGEMENT PLANNING

Mineral considerations in land-management planning are detailed in the previously referenced "Minerals Planning Handbook." In summary, mineral inputs are in response to the five items listed in the NFMA regulations (36 CFR 219.12(J)):

1. Active mines within the area of land covered by the forest plan;
2. Outstanding or reserved mineral rights;
3. The probable occurrence of various minerals, including locatable, leasable, and common variety;
4. The potential for future mineral development and potential for withdrawal from development; and
5. The probable effect of renewable resource allocations and management on mineral resources and activities, including exploration and development.

The minerals program representative to the ID team is generally the person responsible for

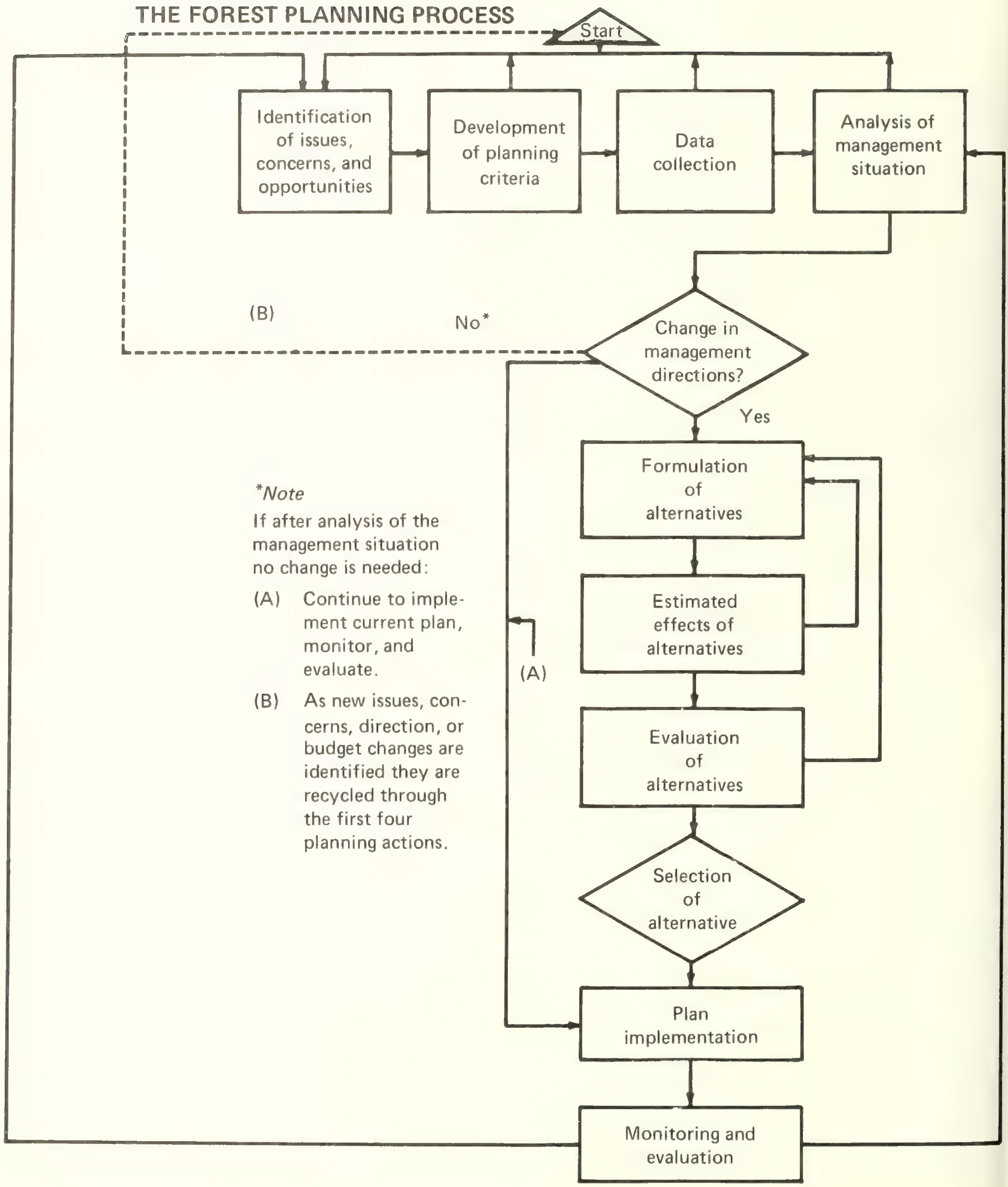


Figure 9. The land-management planning process.

Figure 10. Biologists insure that important wildlife habitats, such as this elk calving area, are considered in the forest plan.

roviding information about the mineral resource and for representing the needs of the mineral resource during the planning effort. This person provides forecasts of expected mineral activity on, and adjacent to, the Forest. The forecasts estimate the type, magnitude, and duration of mineral activities expected in the planning area and provide the best information available as to when and where the mineral activity is expected. The estimates are useful for focusing the attention of the ID team (including the biologist) on specific land areas where mineral activity is expected.

WILDLIFE REQUIREMENTS IN LAND-MANAGEMENT PLANNING

The NFMA directs that certain wildlife values be represented in the forest plan. When the biologist participates in land-management planning, he works with other resource specialists to make sure that these wildlife requirements are provided for (fig. 10). The NFMA regulations require that wildlife habitat goals be identified to maintain viable populations of all existing native vertebrate species in the planning area and to maintain and improve habitat of management indicator species. A viable population is one that has adequate numbers and dispersal of reproductive individuals to insure the continued existence of the species population on the planning area. Management indicator species that represent all existing native vertebrates in the forest being planned must be selected. According to NFMA regulations, management indicator species are species identified for land-management planning purposes that may include: (1) threatened and endangered plant and animal species in the area; (2) species with

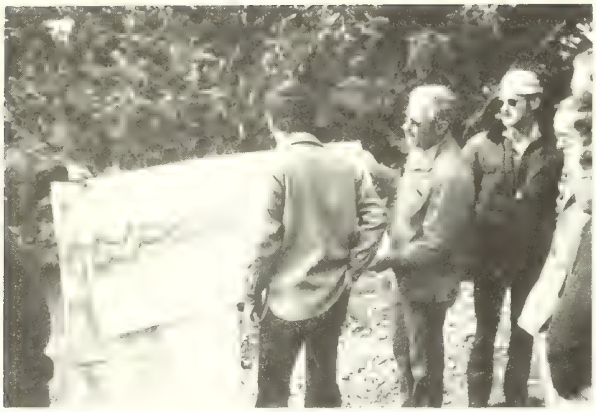


Figure 11. On-the-ground discussions of industry's plans and wildlife needs are an important step in the planning process.

special habitat needs that may be influenced significantly by planned management programs; (3) species commonly hunted, fished, or trapped; and (4) species whose population changes are believed to indicate effects of management activities on other species found in the area.

To carry out NFMA directives the biologist identifies the size of the area upon which the wildlife goals can be met. Objectives for wildlife on suitable habitat units are prepared for all of the forest's wildlife habitat acres. Objectives are also stated that address the minimum acceptable conditions assuring population viability. In addition, management practices, by ecosystem, are included in the forest plan.

Objectives may vary by planning alternative, each responsive to a different management emphasis. The biologist determines the minimum portion of the forest suitable for application of the minimum acceptable habitat conditions for management indicator species. If the habitat quantities and qualities are underrepresented, population viability would not be maintained, and legally required conditions for wildlife would not be provided.

PROJECT IMPLICATIONS

When an operating plan for a mineral project is submitted to the Forest Service, the forest plan provides objectives and guidelines to consider in making recommendations about the operator's plan. Goals, objectives, and standards that may apply include:

1. Area-specific population and habitat objectives that are compatible with Federal laws, such as the NFMA and the Endangered Species Act, management emphasis of the forest plan, or other approved land-management plans.
2. Minimum acceptable conditions for wildlife.
3. Management practices by ecosystem.

Forest Service representatives can meet with industry officials before mineral development begins to examine the objectives for wildlife documented in the forest plan, and negotiate reasonable standards for protecting wildlife (fig. 11). The nature of the negotiations may differ, depending on whether the minerals are classified as locatable or leasable.

When locatable minerals are involved, the authority of the Forest Service provides for the protection of nonmineral values against unnecessary or unreasonable damages from mining activities. The authorities are intended to provide protection without unreasonably inhibiting or restricting the activities of prospectors and miners. When leasable minerals are involved, the Government has discretionary authority over issuance of leases. If conflicts between wildlife objectives and mineral activities cannot be resolved through cooperative efforts, legal action may be required.

Chapter 4

PHASES OF MINERAL ACTIVITIES

This chapter explains the phases of mineral development and describes some of the changes that may occur to the surface resource. Based on such an understanding, the biologist—as either a member of, or consultant to, the Forest Service interdisciplinary team that reviews industry's proposed plans—can recommend to the land manager ways to meet wildlife needs while considering mineral and other resources.

For each classification of minerals (locatables, leasables, salables) a brief description of the legal basis for the mineral classification is given, and an explanation, by phase of mining, of expected industry activities is provided. The points covered are, of course, generalizations, and activities will vary by project. Note that under the "salables" section, only the legal basis for the classification is discussed. This is because the development and extraction processes of developing a "salables" mineral project is very similar to a "locatables" project and because new guidelines and regulations are being promulgated for salables. Thus, for specifics with regard to salables, refer to locatables.

LOCATABLE MINERALS

Legal Basis

While locatable minerals are frequently thought of as hardrock minerals, the Mining Law of 1872 actually puts locatables in a broader perspective. Under this law, a locatable mineral is one that is: (1) recognized as a valuable mineral by standard authorities; and (2) is found on public land open to mineral entry in quality and quantity sufficient to render a claim valuable because of mineral content.

Later laws excluded some leasable and salable minerals from this broad definition; however, any mineral not excluded is considered to be locatable. Some specific locatable minerals include gold, silver, lead, tin, and copper. Generally, all valuable metallic mineral deposits are locatable, as are a large group of nonmetallic minerals that have been designated locatable by the Department of the Interior, a Federal or State court, or Congressional legislation. These include borax, feldspar, and gypsum.

Phases of Mining

Generally, locatable mineral deposits are developed through a sequence of mining steps that result in extraction of the mineral and reclamation of the land. A discussion of each step in terms of industry activities follows. Note that the phases of mining described are general, rather than specific to any one locatable mineral.

Furthermore, although the presentation makes the mining phases appear clear and distinct, in actual situations they are not so well-defined, often overlap, occur over extended periods of time, and may include periodic intervals of inactivity. When involved in a mining project, the biologist must possess a working knowledge of the specific mining practices used, as well as the laws and regulations in effect.

While reclamation is discussed as part of the production phase of mining, it may and should occur upon the completion of the surface-disturbing activity on a given land area. For example, when a large, open-pit surface mine is proposed, plans for final land configuration and reclamation are included in the approved operating plan. If an operating plan is necessary, a reclamation plan and bond are required. (In the following discussion, the term "operating plan" is used in a general sense to refer to mining plans and plans of operation.)

Prospecting

Prospecting is a general term for a group of activities that range from regional appraisals to detailed reconnaissance. It can be defined as the search for a mineral prospect—an area that is a

potential site of a mineral deposit based on preliminary exploration.

During prospecting, the area under study can vary from thousands of square miles to one as small as several hundred acres. The following industry activities may occur during prospecting:

1. Basic prefield research projects.
2. Photogeology and remote sensing projects.
3. Geochemical projects (stream sediments, soil samples, and so on).
4. Geologic mapping and sampling (surface and subsurface).
5. Geophysical projects (on-the-ground, underground, and airborne).
6. For hardrock, digging shallow pits and trenches and perhaps surface and underground drilling.
7. Travel over existing roads and off-road vehicle (ORV) use.

Most forms of prospecting are non-surface disturbing or result in only minor impacts to surface resources. These activities are usually undetectable after a few rainstorms or, at most, a couple of growing seasons. In fact, prospecting for locatable minerals may go unnoticed by the Forest Service until claims are staked or the Ranger District is contacted by company representatives. Very rarely is a notice of intent or operating plan required for these prospecting activities.

Resource conflicts or disturbances typically associated with prospecting activities include:

1. Access. Most access involves use of existing roads and trails and/or use of off-road vehicles. The Forest Service may also receive requests to use roads located in closed areas, such as RARE II areas.

2. Helicopter use. In remote regions or in areas regarded as sensitive because of wilderness or wildlife values, helicopters are commonly used and generally result in minimal surface impacts for helipad construction. However, conflicts between recreationists and industry may result when helicopters are used in or near wilderness areas and/or high recreational-use areas.

Exploration

Exploration is the process of investigating target areas in order to discover if an economically viable mineral deposit exists, and if so, to establish its nature, shape, and grade. Exploration is the transitional stage between the pros pecting and development stages.

Exploration activities may range from de tailed surface appraisal to dimensional sampling Project-area size depends upon the minera commodity being sought and can vary fron several thousand acres to less than 20 acres. Th following summarizes activities that may occu during this phase of mining:

1. Compilation and evaluation of prospectin data.
2. Detailed photogeology projects, includin remote sensing.
3. Detailed geochemistry projects, which ma require soil sampling on a closely spaced (50 100 ft) grid pattern.
4. Detailed geophysical projects, includin drilling test holes for subsurface geophysica studies.
5. Detailed surface mapping and sampling.
6. Detailed underground mapping and sam pling.

Figure 12. Considerable access road construction may be needed during exploration.

7. Subsurface mapping and sampling by various drilling methods.

8. Excavation of drill pads, pits, trenches, adits, and shafts.

9. Travel over existing roads, ORV use, reconstruction of existing roads or trails, and construction of new access roads (fig. 12).

10. Additional claims staking.

11. Bulk sampling for metallurgical testing (surface and/or subsurface).

Surface disturbances resulting from exploration activities depend on the method and equipment used and the size and type of the target area. Surface disturbances may be widespread during exploration activities for a number of reasons: The target area is not yet clearly defined; access problems exist; topography creates a barrier; and the exploration methods used result in widespread disturbances.

As exploration activities intensify, impacts on other resources generally increase. However, the surface effects from these activities can usually be reclaimed so that:

1. Unnecessary erosion is prevented.
2. Visual impacts are reduced.
3. Disturbed lands are reshaped and converted back to a productive status.
4. Safety hazards are eliminated.

During exploration, contact between industry and the Forest Service increases as the project expands. In the early stages of exploration, notices of intent, exploration permits, and operating plans are routinely handled by the land manager. Most industry contacts are of an informational nature involving questions concerning Forest Service policy, regulations, and requests for information to assist the operator in complying with Forest Service management policies and regulations.

Feasibility Studies/Operating Plan

Upon completion of exploration, industry determines if the property(ies) warrants further development. If it does, the rate and period of development are considered. Future development will proceed in accordance with overall company plans, cash-flow limitations, market projections, and so forth. If the evaluation is positive and the operator decides to proceed to the development phase, an operating plan will be filed with the appropriate administrative agencies.

Regulations require an operator conducting prospecting, exploration, development, production, or mineral processing operations on National Forest System lands to file a notice of intent and/or operating plan when the proposed work will cause a significant disturbance to the surface resources. Development operations normally cause significant surface disturbance and therefore require an approved operating plan.

The scope of the operating plan varies with the size, location, and complexity of the activity. Its size may range from a few form-filled pages to a lengthy document supported by several volumes of technical memoranda. Basically, the plan identifies the claimant and describes the operator's proposed operation, access routes, waste disposal plans, environmental protection measures, and reclamation program.

To develop a major environmental analysis, baseline data must be collected; generally, this is the responsibility of the Forest Service, although at times the industry may assist in data collection through third-party arrangements. Information gathered includes, but is not limited to:

1. The site's geologic characteristics.
2. The type of soil and vegetation present on the site prior to mining.
3. Wildlife and fisheries data.
4. Cultural resources.
5. Water (surface and subsurface).

Baseline data are used as a yardstick to measure the success of reclamation and compliance with the approved operating plan.

Before industry can proceed with development, the necessary reclamation bond must be deposited with the Forest Service and the operating plan must be approved by the authorized officer(s). If and when necessary, industry may submit amendments modifying the plan, or the Forest Service may require industry to update the operating plan to satisfy regulatory requirements. Such amendments may be made throughout the mining process.

The Forest Service's heaviest involvement in the mining project probably comes during the review and approval process for the operating plan and subsequent compliance inspections. For example, during operating-plan review, the Forest Service prepares an Environmental Assessment (EA) based on the plan, or if neces-

sary, an Environmental Impact Statement (EIS).

Forest Service staff members must understand their responsibilities and regulatory authority relative to the type of mineral being developed. For example, when the Forest Service receives an operating plan for locatable minerals, 36 CFR 228 (formerly 36 CFR 252) regulations require that the Forest Service promptly acknowledge its receipt to the operator, and within 30 days of such receipt, the authorized officer must evaluate the operating plan and:

1. Notify the operator that the plan is approved;
2. Notify the operator that the proposed operations are such as not to require an operating plan;
3. Notify the operator of any changes in, or additions to, the operating plan deemed necessary to meet the purpose of the regulations;
4. Notify the operator that the plan is being reviewed but that more time, not to exceed an additional 60 days, is necessary to complete the review setting forth the reasons why additional time is needed; or
5. Notify the operator that the plan cannot be approved until a final Environmental Impact Statement has been prepared and filed with the Council on Environmental Quality. If the Forest Service land manager determines an Environmental Impact Statement is required, the Forest Service is responsible for preparing the EIS.

Development

Development can be defined as the preparatory work necessary to facilitate the extraction and/or processing and transporting of the proven mineral reserve. Note that production may or may not accompany development. Indirectly, development activities occur throughout the life of many mineral operations. Hence, development and production operations frequently take place at the same time on different parts of a project.

Industry activity during the development phase includes, but is not necessarily limited to, opening up the deposit for underground access and installing surface and subsurface facilities and equipment needed for mineral extraction, processing, and transportation (fig. 13).

Following or during development work, the operation may move into the production phase. However, the company may decide to delay production. Reasons for delaying might include: (1) additional property, water rights, surface rights, and so on, may need to be acquired; (2) better market conditions may be anticipated; (3) equipment or personnel problems; (4) contract problems; (5) cash-flow considerations; or (6) an assortment of unrelated problems.

Development work is generally a transitional stage between exploration and production activities, but often continues after production has begun. Development usually causes the most surface disturbance, but the acreage impacted is generally well-defined and limited to the area of future operations. As it does for all surface-disturbing mining activities, the Forest Service must monitor the project during development to make sure the operating plan is adhered to, and to determine if any changes are needed in the plan.

The Forest Service biologist should also be aware that as industry's exploration staff leaves and construction workers enter the area, people-related impacts will likely increase because of the larger numbers of people using the forest. To establish a communication link, the biologist should become acquainted with construction and mining crews.

Production/Reclamation

Because production and reclamation may occur simultaneously, they are discussed together here. However, reclamation should occur whenever the surface-disturbing operations are completed for any land area.

Production: Production (or mining) is the process of extracting and/or processing and transporting mineral products from the site to market. Hardrock minerals are extracted by underground, open pit, or placer mining methods. The underground method causes the least amount of surface disturbance.

After the mineral has been extracted, it is milled and then transported to a smelter for additional processing. The mill may or may not be located on the property. In many cases, the raw ore is sent to a custom mill. Production may continue for 20 years or more and may involve periodic openings and closings of the operation for various reasons.

Normally, little additional surface disturbance occurs during the production stage, except within the actual operating, waste-disposal, or tailings

Figure 13. Facilities needed to operate the mine are installed during the development phase.

ond areas. Thus, Forest Service work will essen-ially involve monitoring industry activities. lowever, operating plan modifications may be ecessary in some cases.

Reclamation: Reclamation is the process of eturning disturbed land to a predetermined orm and productivity standard. Reclamation is ne responsibility of the operator, and the com-any's efforts must meet the requirements set orth in the approved reclamation plan. If they o, the Forest Service will release the reclama-on bond, but if not, and the company refuses o redeem its reclamation responsibilities, the orest Service will use the bond to complete the greed-upon reclamation. Reclamation activities nclude:

1. Shaping and grading spoils.
2. Replacing stockpiled topsoil.
3. Fertilizing and planting a vegetative cover.
4. Mitigating water and air pollution.
5. Protecting selected animal species.
6. Reclaiming abandoned transportation and tility corridors.
7. Reclaiming tailing dams and waste-disposal mbankments, and closing off mine drainages.
8. Re-establishing natural drainages whenever ossible. The cost and complexity of reclamation procedures vary greatly depending on the extent of the operation and the period of time required to achieve desired results.

Postmining

Postmining is the period following mineral extraction and initial reclamation work. During this time, the mining operator is required to monitor the success of the reclamation program and re-treat problem areas. Road reclamation may also occur during this time. The object of postmining monitoring is to assess whether the reclamation goals agreed to in the operating plan have been reached. If so, the operator is released from the reclamation bond.

The length of time during which the operator is responsible and liable for the success of the reclamation effort varies, but often continues for several years after the last year of augmented seeding, fertilization, irrigation, or other work. Generally, the time period is stated in the operating plan. Once released from the bond, industry activities cease on the site.

One note: Temporary shutdown of mining operations may also occur. This could happen if, for example, the operation were endangering life or irreversibly damaging surface resources. In these cases, reclamation work is performed to

Figure 14. Helicopters are commonly used during preliminary investigation.

Figure 15. Vibrosis trucks, or "thumpers," are used to shock the earth to determine oil-bearing formations in oil and gas exploration.

correct the problem, after which the operation may reopen.

LEASABLE MINERALS

Legal Basis

Under the Mineral Leasing Act of 1920, certain minerals were withdrawn from location (as provided for by the Mining Law of 1872) and were placed under the Leasing Act. This act provides for mineral development through prospecting permits and leases, rather than claims-staking. No permanent rights can be acquired from the U.S. Government; instead, only the right to explore for and mine the specific leasable mineral covered by the lease or permit is granted.

These leasable minerals, as designated by the 1920 act, include: oil, gas, coal, oil shale, sodium, potassium, phosphate, native asphalt, solid or semisolid bitumen, bituminous rock, oil-impregnated rock or sand, and sulfur in Louisiana and New Mexico. Oil and gas are generally thought of as the most common minerals designated as leasables.

Phases of Mineral Activity

Depending on the type of leasable mineral under consideration, the phases of mining will vary. For example, coal and phosphate are mined similar to hardrock minerals; however, oil and gas are explored for and produced by drilling and pumping. The following discussion focuses on the steps involved in oil and gas exploration, development, and production since they are the most common minerals designated as leasables. Again, it should be remembered

Figure 16. Blasting effects during seismic activity can temporarily affect wildlife use patterns.

ıat these are general phases; they will vary from .ineral to mineral, and the phases may overlap. owever, the industry activities covered will ısually occur at some point in leasable-minerals ɜvelopment.

ɾeliminary Investigation/Mineral Leasing

Preliminary investigation for oil and gas can ɜ defined as the search for environments favor-ɔle to the accumulation of oil and gas. The ɪtent of preliminary investigation is to deter-ine whether an area warrants more detailed ɪploration.

During preliminary investigation, the area ıder study can vary from thousands of square iles to an area as small as several hundred ɪres. The following industry activities may ɪcur during this phase:

1. Airborne surveys (fig. 14).
2. Geochemical surveys.
3. Geologic surveys, mapping.
4. Geophysical surveys, including the explosive methods, the thumper method, the vibrator method, gravity, and other methods (fig. 15, 16).

If preliminary investigation identifies an area that warrants more detailed study, a lease is normally acquired. Generally, the oil company acquires a lease prior to much surface disturbing work. The operator applies for the lease from the State office of the BLM, or in the Eastern United States, the Eastern States Land Office of the BLM. Before issuing a lease for National Forest System lands, however, BLM sends the application to the Forest Service for recommendation or consent, depending upon the status of the land (public domain or acquired) and the mineral commodity (coal, geothermal, etc.).

When leases are applied for, the Forest Service is involved in the evaluation through a memorandum of understanding between the

Departments of Agriculture and Interior. The Forest Service assesses possible effects of the development activity on other resources and then makes recommendations concerning the lease. An important outcome of the Forest Service review is the identification of specific surface protection measures, which are attached to the lease as stipulations. Stipulations are attached to all leases (standard stipulations have been developed for some commodities). In some cases, where unique surface situations exist, special stipulations are required or are included as part of the lease terms.

Once a lease is issued, the U.S. Geological Survey supervises onsite operations through a cooperative agreement with the Forest Service, which provides surface-resource information for planning and administration purposes. By regulation, the USGS is directly responsible for the mineral operation itself while the Forest Service retains administrative authority in emergency situations, such as oil spills, that could endanger other resources.

Exploration

Exploration for oil and gas is the process of further studying target areas in order to discover if an economically viable deposit (reservoir) exists, and if so, to establish its nature, shape, and potential production capabilities. Exploration is transitional from preliminary investigation; however, some preliminary investigation activities may continue, but the area of interest is usually smaller.

The following summarizes industry activities that may occur during this operational phase:

1. Stratigraphic tests, which involve drilling relatively shallow holes to supplement seismic data.

2. Lease acquisition or additional lease offers to firm up the amount of property to be developed.

3. Wildcat drilling, which is a well drilled in unproven territory to test the area for oil or gas (fig. 17).

4. Travel over existing roads, ORV use, construction of new access road, and/or the reconstruction of old roads and trails.

5. Campsite establishment and building construction (in remote areas).

Feasibility Studies/Operating Plan

If exploration work is successful, industry generally conducts a feasibility study to determine if economic conditions warrant development. A formal feasibility study includes an economic analysis of the rate of return that can be expected at a certain rate of production. If the results of the study are favorable, the operator may decide to proceed to the development phase. The operator initiates this phase by submitting an operating plan. Generally, the request (or operating plan) describes the operator's proposed mining methods, access routes, waste disposal plans, environmental protection measures, and reclamation program.

To evaluate the plan environmentally, the Forest Service requires baseline data. Although the Forest Service is responsible for collecting this information, it is often done by industry

Figure 17. Typical drill pads require 2-4 acres.

Figure 18. Pumps are installed during development.

through a cooperative agreement. Information gathered by the various disciplines includes:

1. The site's geologic characteristics.

2. The type of soil and vegetation present on the site prior to drilling.

3. Details of regional wildlife in the area.

4. Cultural resources.

5. Hydrologic factors (surface and subsurface).

Baseline data are used as a yardstick to measure environmental impacts and the success of reclamation.

Before industry can proceed with development, the operating plan must be approved by the authorized Government officials. If necessary, either industry or the Forest Service may submit amendments modifying the plan to satisfy regulatory requirements. Such amendments may also be made throughout the development and mining processes.

Development

After a decision is made to proceed with the project and the operating plans and leases are in place, development work begins. In oil and gas operations, development is defined as the work of preparing a reservoir for extraction and transportation. Industry activities might include:

1. Opening up the reservoir by development drilling, and installing the equipment needed for extraction (fig. 18).

2. Extensive drilling of the resource to determine its grade, volume. and boundaries.

3. Improvement or construction of roads, pipelines, utilities, and mud pits (fig. 19).

4. Preparatory work for processing.

5. Construction or arrangements for workforce housing.

6. Submission of amendments to the approved operating plan, if necessary.

Production can begin immediately following development; however, the company may choose to delay production. Reasons for such delay might include: (1) Additional property, water rights, surface rights, et al., may need to be acquired; (2) better market conditions may be anticipated; (3) equipment or personnel problems may arise; (4) contract problems may need to be worked out; (5) cash flow problems may exist; or (6) an assortment of unrelated problems might best be solved by simply delaying the project. Also, with leasables, another reason for delay is that pipelines or transport facilities may be lacking or a market has yet to be established.

Production/Abandonment

As production closes down on certain areas, they are reclaimed while other areas continue to produce. Therefore, because production and abandonment often occur simultaneously, they are discussed together here.

Production: Production is the process of extracting and transporting mineral products from the site to a processing location or to market.

Extraction of oil and gas involves:

1. Continued drilling and development of the field.

2. Installation of a pressure maintenance system.

Figure 19. Most roads (left) and improvements (right) are constructed during the development phase.

3. Establishing means for waste disposal.

4. Installation of a secondary and tertiary recovery system.

5. Installation of communication and production systems.

6. Building, or otherwise establishing, facilities for housing the workforce.

Abandonment: The abandonment phase of a leasable (oil and gas) project is generally comparable to the reclamation phase of a locatable or salable project. Industry activities during abandonment of individual wells may start early in a project and continue through the depletion of the field, with the bulk of activity occurring at the conclusion of the project. Industry activities during abandonment generally include:

1. Removal of equipment, buildings, and facilities.
2. Field cleanup.
3. Well abandonment and plugging.
4. Elimination of hazards.
5. Surface reclamation, including landscaping, reseeding, and other erosion control measures.

SALABLE MINERALS

Legal Basis

Mineral materials are disposed of from National Forest System lands under the authority of the Materials Act of 1947, as amended by the Act of 1950 and the Act of 1955. Called salables, these materials may be acquired only by purchase or free-use permit. Salable mineral (common varieties) are sand, stone, gravel pumice, pumicite, cinders, and some clay.

All mineral material must be appraised an sold at not less than the appraised value, excep material disposed of to Federal or Stat agencies, municipalities or nonprofit organiza tions. These agencies and organizations ma receive the material without charge, provide the materials are not used for commercial pur poses or resale and provided the site is reclaime to productive use.

If the appraised value of the material exceed $1,000, it must be sold to the highest bidder a public auction. Notice of sale must be publishe once each week for four consecutive weeks in newspaper having general circulation in th county in which the material is located. Th competitive sale may be by sealed bid o auction.

If the appraised value is $1,000 or less, th material may be sold to a qualified applicant b Special Use Permit; however, no more tha $1,000 worth of materials may be sold to an one applicant in any one area in any one perio of 12 consecutive months. (Above three para graphs from "Handbook of Mineral Law," b Terry S. Maley, second edition, revised 1979.)

Although these materials are sold, the U.S Government still has the right to use the surfac and issue permits. Permits, leases, and contract will require reclamation of disturbed land, a well as an adequate bond sufficient to insur reclamation.

Chapter 5

LINKING ACTIVITIES, IMPACTS, AND EFFECTS: A FRAMEWORK FOR ANALYSIS

This chapter presents an analytical framework for relating mineral activities to changes in the environment and to subsequent effects on wildlife and their habitat. It provides the biologist with a tool for systematically analyzing these effects.

Each phase of mineral activity has the potential for impacting[20] (changing) the environment, causing subsequent changes in the wildlife habitat and, in some cases, wildlife behavior and populations. The analysis (identification and quantification of the impacts and effects) and the evaluation (determining the significance of the effects) are somewhat complex tasks that require the biologist to take a disciplined and thorough approach to make the job as objective and professional as possible.

As a member of an ID team performing an assessment of a minerals project, the biologist provides information on the following items to the team:

1. Wildlife habitats and species present.
2. Wildlife habitat/species relationships.
3. Specific characteristics of the proposed activity that are pertinent to wildlife.
4. Consequences to wildlife from the changes resulting from the project, directly or indirectly.
5. Contributory effects on wildlife from natural processes, such as plant succession.
6. Cumulative effects on wildlife from all land-management activities in the project area, and effects that occur on the broader area for wide-ranging and/or migratory species.

In addition, the biologist presents alternative measures needed to provide for wildlife and habitat and to accomplish the objectives set forth in the forest plan. Along with this information, the biologist identifies wildlife trade-offs and makes recommendations to the land manager.

ACTIVITY/IMPACT/EFFECT RELATIONSHIPS

The effects of mineral activities on wildlife are determined by:

- The type of exploration and extraction processes.
- The characteristics of the site.
- The wildlife habitat and species present.

Each operation needs to be assessed on a site-specific basis, considering the activities and impacts expected by each phase of operation. In some cases, when multiple activities are occurring concurrently or in phases, the cumulative effects also need to be considered. Some points to keep in mind are:

1. Impacts can be a primary result of the mineral operation, such as loss of habitat, or the effect can be a secondary one, such as occurs when the human population of the surrounding area grows and hunting and fishing pressures increase.
2. Impacts and effects can be direct and affect the animal, such as an increase in road kills, or they can be indirect and affect habitat or some aspect of the total needs of the species.

[20] As used in this document, the term "impact" means change of an existing condition and has neither negative nor positive connotations.

3. The impacts can occur either onsite (fig. 20) or offsite (fig. 21). Ancillary facilities, such as pipelines and powerlines, are often involved in mineral activities.

4. The effects on wildlife that result from the changes can be considered positive for some wildlife species (new water resources for wildlife), negative for some species (harassment of wildlife during the mating season), or neutral for still other species (a slight alteration of a migration route).

5. The effects can be considered as site specific (for an individual project) or cumulative (for many projects in a given area).

6. Effects on habitat can be classed as those that affect the suitability of the habitat (food, cover, water) and those that affect the availability of the habitat (people/wildlife encounters, noise).

7. Effects on wildlife can influence behavior (change in pattern of use) or directly affect population levels.

8. Increased human presence can result in more people/wildlife encounters and higher noise levels that may affect the availability of the habitat. Increased population may also result in more accidental wildlife deaths and perhaps poaching that would directly affect the wildlife population.

Table 5 summarizes some of the effects on habitat and on animals that may occur as a result of mineral activities.

GENERAL CONSIDERATIONS

The biologist should keep in mind a number of general considerations when assessing the effects of mineral activities on wildlife. The following list of considerations is not all-inclusive. However, it does identify certain items to consider in the analysis.

1. Activities and impacts by phase of mineral operation. The effects of mineral operations on wildlife are determined by the type of exploration, the extraction process, the characteristics of the site, and the wildlife present. Therefore each operation needs to be assessed on a site-specific basis. The biologist, working with the minerals specialist, identifies the activities in the various phases of the project and the impacts that are expected. The season of the year in which the activities are likely to occur should be noted, as the time of year is sometimes significant in determining wildlife effects. This description of activities and impacts, by phase of activity, provides the basis for considering the effects on various wildlife species. The tables at the end of this chapter provide examples of these descriptions.

Figure 20. Drilling activity can affect wildlife use patterns.

Figure 21. Offsite facilities, such as powerlines and pipelines, can affect wildlife and their habitat.

2. Different effects by species. The biologist must identify which species are expected to be positively affected, adversely affected, or not affected by the proposed activity. The duration of the effect should also be determined (see point 4).

3. Duration of effects. The effects of some mining projects are short-term or temporary, while others may have long-term or permanent consequences. Determination of the longevity of the expected effects helps the biologist recognize the significance of the activity to wildlife.

4. Scope of effects. Proposed activities differ in intensity of effects and extensiveness of the area affected. The intensity of the effect of a particular activity may differ, depending on the phase of activity. For example, in certain types of operations, people/wildlife encounters may be greater during development than exploration even though the area affected is more limited. Also, an intensive activity may not be important to a large variety of wildlife species if the habitat area impacted is small. It is also possible that an extensive activity may have minimal effects on wildlife, even if it occurs over a large area.

5. Season of activity. The season of the year in which the activities will occur should be considered. Activities that may have significant consequences to some wildlife during a particular season, such as spring calving season for elk, may have less consequences if conducted during another period of the year. Also, some activities may have negligible effects on resident species in the area but could affect migratory species that visit the area during a particular season.

6. Adaptability of wildlife species present in the area. The adaptability of species present is analyzed to determine their vulnerability to expected mining activities. For example, the analysis might consider the effects of increased noise levels and of habitat availability (fig. 22). This analysis could include an examination of the mobility of species present and opportunities for habitation in adjacent areas. The home range of the species involved usually will dictate the size of the study area required, but for

Table 5.—*Impact/effect relationship*

Result of mineral activities (impacts)	Effects on habitat	Effects on animals
A. Direct (animal)		
1. Changes in animal demand due to increased human population • Increased hunting and fishing • Accidental wildlife deaths • Poaching		Population • Direct mortality
B. Indirect (habitat)		
1. Changes in location, magnitude, frequency, and duration of human presence	Habitat availability • People/wildlife • Noise	Behavioral • Changes pattern of wildlife use Population • If habitat is essential, could affect population
2. Changes in: • Topography • Soils • Vegetation • Water supply • Water quality (surface) • Water quality (subsurface) • Air quality	Habitat suitability • Food • Cover • Water • Air	Behavioral • Changes pattern of wildlife use Population • If habitat is essential, could affect population

Figure 22. The adaptability of species is an important consideration.

Figure 23. Riparian areas support a diversity of fish and wildlife.

migratory and wild-ranging species, a broader land area must be considered.

7. *Sensitivity of the area in relation to wildlife.* Some areas may be extremely sensitive to alteration because they contain restricted habitats of specific wildlife species. (An example of a restricted habitat is a riparian zone in a predominantly arid region, as shown in figure 23.) Even low-intensity or small-acreage projects in areas of this type could result in significant consequences to some wildlife species. The requisites for wildlife, such as food, cover, water, reproduction, and migration routes, should be evaluated to identify the area's level of sensitivity. Also, the presence of federally classified species and their habitats should receive particular attention in the assessment.

8. *Resiliency and tolerance of vegetation.* If the vegetation is to be altered or exposed to stress, such as air pollution, the degree of various plant species' resiliency and tolerance to the

Figure 24. Mineral and energy developments can result in new towns.

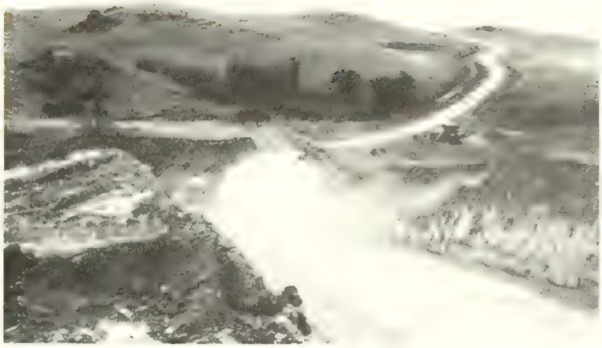


Figure 25. Improved access for mineral activities can affect wildlife use patterns over a large area.

disturbance may need to be analyzed. In areas of high precipitation, for example, disturbed areas will normally be revegetated more readily than in arid regions. The type of vegetation and its ability to recover from disturbance are related to the duration of the effect.

9. Habitat diversity—minimum habitat requirements and viable populations of wildlife species. The quantity, quality, and distribution of habitat components required by the wildlife species in the area should be considered. The biologist must determine if the requisites necessary to maintain viable populations in the area will be present when the project is in operation and after it is completed. This analysis may require an examination of onsite and offsite areas influenced by the project.

10. Potential for the area's rehabilitation. The potential for habitat rehabilitation and/or opportunities for improvement should be determined for projects expected to impact wildlife habitat.

11. Contributory effects. Effects that occur naturally and have no relationship to the activity, such as plant succession, must be examined to determine the contributory effect on wildlife.

12. Consequences and risk associated with unplanned events. Certain projects may hold risks for wildlife because of unplanned but possible events, such as sedimentation or chemical pollution of streams. The likelihood of such events occurring and the consequences to wildlife should be considered.

13. Human population growth. Whether a project is expected to influence human population growth is an important component of the biologist's assessment. The level of human population affects the patterns of consumptive and nonconsumptive use of the wildlife resource, the degree of harassment, and secondary impacts such as changes in water quality and quantity (fig. 24).

14. Accessibility of the area. Increased accessibility to previously remote areas may significantly affect some wildlife species because of increased encounters with people (fig. 25). Therefore, the impact of increased people/wildlife encounters may need to be evaluated.

15. Cumulative effects. The effects of all other Forest activities and resource uses in relation to proposed mineral activities are an important part of the wildlife analysis. The cumulative effects of mineral projects that are sequential in nature—for example, oil and gas exploration leading to development that results in production—should be considered.

PERSPECTIVE

The following sample charts (tables 6-9) for oil and gas and hardrock operations show typical activities that occur by phase of operation and some general ratings as to the magnitude and duration of the impacts. Note that the ratings in tables 8 and 9 are general, and impacts for any given operation or site may differ greatly. The biologist working on a project may want to develop similar charts showing planned activities and expected impacts.

Table 6.—*Typical activities likely to occur at various phases of oil and gas development*

Activities	Phases				
	Preliminary investigation	Exploration (Primary/seismic)	Development (Including wildcat wells)	Production/ abandonment	Post-operation
Helicopter use	X	X	X		
Explosives	X	X	X		
Existing road use	X	X	X	X	X
Road construction	X	X	X		
Site construction			X	X	
Water			X	X	
Wastes			X	X	
Living quarters			X	X	
Field development					
Wells		X	X	X	
Pipelines			X	X	
Power lines				X	
Abandonment					
Wells and facilities			X		X
Transportation network					X

Table 7.—*Typical activities likely to occur at various phases of mining—hardrock minerals*

Activities	Phases				
	Prospecting	Exploration	Development	Production/ reclamation	Postmining
Helicopter use	X	X			
Explosives	X	X	X	X	
Existing road use	X	X	X	X	X
Road construction	X	X	X	X	
Site construction			X	X	
Water			X	X	
Wastes			X	X	
Living quarters			X	X	
Power lines			X	X	
Reclamation				X	X

Table 8.—*Magnitude and duration of selected impacts from mineral activity on wildlife oil and gas*

Types of activities	Impacts: Human/ wildlife encounters	Noise level	Vegetation	Water	Soil	Air quality
Seismic exploration						
• Helicopter	M/ST	H/ST	L/ST	N	L/ST	L/ST
• Ground rigs (explosives)	M/ST	H/ST	L/ST	L/ST	L/ST	L/ST
• Ground rigs (drill)	M/ST	M/ST	L/ST	M/ST	L/ST	L/ST
Exploratory drilling						
• Road access	M/INT	M/ST,L/INT	M/ST,INT	M/ST,INT	M/ST,INT	L/INT
• Pad development	M/ST	M/ST	M/INT	L/ST	M/INT	L/INT
Water	L/ST	N	N	M/INT	N	N
Wastes	N	N	M/INT	M/INT	M/INT	L/INT
Living quarters	M/INT	L/INT	L/INT	M/INT	L/INT	L/INT
• Drilling and servicing	H/INT	M/INT	L/INT	M/INT	L/INT	M/INT
Field development						
• Roads	M/LT	M/INT	M/INT	M/INT	M/LT	M/INT
• Wells	M/INT	M/INT	M/INT	M/INT	M/INT	M/INT
• Pipelines and tanks	H/INT	L/INT	M/INT	M/INT	M/INT	L/INT
• Servicing	H/INT	M/INT	N	N	N	M/INT
Production						
• Roads	M/LT	N	M/LT	L/LT	L/LT	L/LT
• Pipelines and tanks	L/LT	N	L/LT	L/LT	L/LT	N
• Servicing	M/LT	L/LT	N	N	N	L/LT
Postmining	M/INT	L/ST	M/ST	N	M/ST	N

Impact Key: **Magnitude*** — N = None, L = Low, M = Moderate, H = High

Duration — ST = Short term (1 day to 1 month), INT = Intermediate (1 month to 2 years), LT = Long term (2 years to 40 years)

Relative rankings for this commodity only. These ratings are relative in nature and ratings for any given activity or site may differ greatly.

Table 9.—*Magnitude and duration of selected impacts from mineral activity on wildlife—hardrock minerals, major, long term*

Types of activities	Impacts: Human/ wildlife encounters	Noise level	Vegetation	Water	Soil	Air quality
Access and transmission corridors						
• Access roads	M/LT	M/LT	M/LT	L/LT	L/LT	L/LT
• Haul roads	H/LT	M-H/LT	H/LT	M/LT	M/LT	M/LT
• Slurry lines	M-H/LT	L/LT	M/LT	L/LT	L/LT	N
• Conveyors	M-H/LT	L/LT	L/LT	L/LT	L/LT	L/LT
• Electric lines	L/LT	N	L/LT	N	L/LT	N
• Railroads	H/LT	H/LT	M/LT	L/LT	M/LT	M/LT
Mine development						
• Pit development	H/LT	M-H/LT	H/LT	M/LT	H/LT	M/LT
• High walls	H/LT	M-H/LT	H/LT	M/LT	H/LT	M/LT
• Waste dumps	M/LT	N	M/LT	M/LT	M/LT	L/LT
• Storage—ore and top soil	L/LT	N	M/LT	M/LT	M/LT	L/LT
Ancillary improvements						
• Office, warehouses	M/LT	M/LT	L/LT	L/LT	H/LT	L/LT
• Shops, storage	M/LT	M/LT	L/LT	M/LT	H/LT	M/LT
• Onsite living	M/LT	M/LT	M/LT	M/LT	H/LT	L/LT
• Mill site	H/LT	M/LT	M/LT	L/LT	M/LT	M-H/LT
• Tailing ponds	L/LT	N	L/LT	M/LT	L/LT	L/LT
Postmining	N	N	L/LT	L/LT	L/LT	N

Impact Key: **Magnitude*** — N = None, L = Low, M = Moderate, H = High

Duration — ST = Short term (1 day to 1 month), INT = Intermediate (1 month to 2 years), LT = Long term (2 years to 40 years)

*Relative rankings for hardrocks only. These ratings are relative in nature and ratings for any given activity or site may differ greatly.

Chapter 6

POTENTIAL EFFECTS AND MITIGATIONS

If the analysis of a company's operating plan shows that mineral activity is expected to affect wildlife, the significance of these effects must be evaluated and management strategies must be developed to protect the resource. In this respect, the biologist performs two functions: (1) reviewing the company's operating plan to evaluate the adequacy of the proposed mitigation measures; and (2) if necessary, suggesting revisions to the plan and recommending appropriate mitigation measures. Although mitigation measures are identified in the operating plan before the mineral project begins, adjustments can be made to the plan during operations if necessary.

Throughout the evaluation phase, the biologist will be faced with questions involving the significance of the effects and appropriateness of mitigation measures. Some of these considerations are:

1. Legal implications. Expected effects on (1) Federally classified species and (2) water quality are two major areas of importance in terms of legal mandates for surface-resource management. The legal implications of mineral law and regulations are particularly important when apparent conflicts between wildlife mandates and the statutory rights of the miner must be resolved (see chapter 2).

2. Compatibility of the activities with formal wildlife allocations and management objectives in the project area. It is important to consider broad-level planning documents, such as the forest land-management plan and other comprehensive plans, when evaluating the expected effects on wildlife. Evaluations need to consider not only the expected changes to the "existing condition," but also how the project might affect the ability to accomplish the objectives in the forest plan.

3. Value and uniqueness of habitat present. The value and uniqueness of the habitat in an area is an important consideration. For example, limited wetland and riparian habitat in an arid region has a greater value to wildlife than similar habitats in regions with heavy rainfall. The presence of important transition areas between habitat types should also receive special emphasis in the evaluation, since the number of species present in transition areas is greater than in surrounding areas.

4. Economic, social, and cultural value of the species in the area. These value judgments involve an analysis of onsite consumptive and nonconsumptive use of wildlife in the area, and offsite use of migratory species.

5. Appropriateness of mitigation measures. To determine appropriate mitigation measures, the biologist evaluates:

- The degree to which the effect can be minimized.
- The availability and practicality of technology to implement the proposed mitigation measures.
- The expected success of each procedure in protecting or benefiting wildlife.
- The relative cost of achieving each level of protection—for example, the cost of the best protective measures versus the cost of achieving minimal acceptable standards.

Although mineral activity may present some opportunities for wildlife habitat improvement, the focus of this chapter is on lessening adverse effects. Chapter 7 focuses on opportunities for wildlife.

To provide the biologist with a process for evaluating and mitigating potential adverse effects, this chapter discusses the types of effects that may occur, and suggestions for minimizing the effects. It is not the intent of this guide to provide a detailed discussion of each type of effect nor to suggest that

"standard" mitigation measures exist for all projects. Effects and mitigation measures need to be considered on a case-by-case basis. The U.S. Fish and Wildlife Service (Office of Biological Services) publication entitled "An Environmental Guide to Western Mining, Part Two: Impacts, Mitigation, and Monitoring," was used as the major source document for information contained in this chapter (FWS/OBS - 78/04, December 1977). A more detailed discussion can be found in that publication.

Figure 26. Vehicle movement and human presence can affect the normal movement and distribution of some wildlife species.

HUMAN/WILDLIFE ENCOUNTERS

Encounters between people and wildlife may adversely affect some wildlife species. The effect may be in the form of harassment or direct mortality of wildlife.

1. Harassment:

Description

Harassment, as used here, is a disruption of animal behavior caused by the actual presence of people or factors associated with their presence, such as noise and ground shock (fig. 26). Harassment can prevent some wildlife from using otherwise suitable habitat. The consequences of harassment can be significant if animals are denied use of habitat essential to their survival, such as winter range for deer.

Potential terrestrial effects

Human presence may have disruptive effects on wildlife during the initial phase of a project. Mineral or wildlife survey work, biological sampling, and drill rig operations are the types of activities that may affect a relatively undisturbed environment. Interruption of big game migration routes is a problem by fenced railroads or highway rights-of-way if no safe passage is provided for the animals.

Installation of electrical transmission lines involves clearing and modifying vegetation during construction and maintenance activities. Maintenance of lines requires periodic human presence and equipment in areas that are normally undisturbed. Also, dissemination of information about presence of Federally classified species may ultimately result in their destruction through indiscriminate and thoughtless visitation and collection by the general public.

The significance of the disturbance will depend upon its degree and the sensitivity of the wildlife species present. In grassland areas, the sphere of disturbance may be larger than in forests where vegetation screens the activity from view and muffles the noise.

Highly mobile animals, such as birds, may react to the disturbance by simply leaving or avoiding the area. However, animals that emigrate to other areas may encounter increased competition for resources with resident animals and may not survive. Most of the smaller, less mobile animals may coexist with the disturbance, but high levels of noise and ground shock may cause small mammals, reptiles, and amphibians to develop abnormal behavior or hearing loss.

Potential aquatic effects

The mere presence of people in a mine area will not usually have as disturbing an effect on aquatic wildlife species as it does on terrestrial species. The adverse effects on aquatic wildlife resulting from an increase in numbers of people are more likely to be in the form of direct mortality (see section 2).

Figure 27. Powerline corridors and structures should be planned to minimize effects on wildlife and their habitat.

Considerations for lessening effects

Depending on the specific impacts expected at a project site, various methods can be used to reduce harassment of wildlife. Some suggestions are:

- Formal programs to increase employee awareness of local wildlife concerns.
- Restricted access to sensitive wildlife areas or closures, if needed.
- Seasonal restriction on human activity during critical periods of wildlife activity in sensitive areas.
- Planning road and utility construction to avoid fawning, nesting, breeding, or other sensitive wildlife areas (fig. 27).
- Avoiding the construction of haul and access roads in areas where raptors are known to nest.
- Screening sensitive wildlife areas from the mining activities through use of vegetation and topographic features.
- Designing and locating fences to provide passages for wildlife.
- Establishing minimum flight elevations for aircraft over sensitive wildlife areas, particularly during exploration or surveying activities.
- Equipping machinery and vehicles with the best available noise and gaseous emission suppression devices.

2. Direct Mortality:

Description

Another effect associated with human/wildlife encounters may be the direct mortality of wildlife. Direct wildlife mortality could result from vehicle-wildlife collisions (onsite and offsite) and from an increase in the harvesting of animals, legal and illegal. Vehicle/wildlife collisions, of course, may also result in human injury or fatalities.

Potential terrestrial effects

Of special concern because of their potential for damaging vehicles and injuring people involved in collisions are big game species such as elk, deer, moose, and pronghorn antelope. Construction of roads in the vicinity of migration corridors, daily movement routes, or riparian areas greatly increases the potential for wildlife-vehicle collisions. High population densities of wildlife (such as mule deer on winter range) in particular areas crossed by roads also increase the likelihood of collisions.

Electrical transmission lines may cause bird mortality through collisions with the lines and support structures, especially in areas where natural obstructions do not exist. In some instances, electrocution may also be a factor.

Potential aquatic effects

Direct mortality of fish during mining operations is primarily limited to stream crossing sites, areas of heavy construction immediately adjacent to or actually in stream channels, and dewatered channels caused by the rerouting of streams. Pressure on game fish populations can be expected to increase as a result of increased recreational fishing by the general public and the miners and their families. In small streams and reservoirs, some depletion of fish stock may take place.

Intensive biological sampling of limited fish habitats near potential mine sites could also deplete local populations. This problem is of special concern in areas where federally classified fish species reside.

Considerations for lessening effects

- Keep fences to a minimum on big game migration routes.
- Design and locate fences to accommodate

the natural movement of big game animals, unless specifically designed to prevent access by wildlife to hazardous areas.

- Plan road construction to minimize likelihood of vehicle/wildlife collisions.
- Where possible, minimize traffic during early morning and late evening hours, especially during critical migration periods.
- Use mass transit to carry employees to and from the mine site.
- Install road caution signs indicating wildlife crossing areas and establish appropriate speed limits.
- Properly design and locate power lines to reduce transmission line/bird collisions and electrocution. Consider underground placement of these lines in particularly sensitive areas.
- Request specific harvest regulations for fish and wildlife in the area. These regulations are set by the appropriate State authorities.
- Inform the workforce of applicable hunting, fishing, and trapping laws.

HABITAT DISTURBANCE

Habitat disturbance occurs when any part of the surface resource is altered during mining. Changes can occur in: (1) vegetation, (2) air quality, (3) water quantity and quality, (4) topography, and (5) soils.

1. Vegetation Loss or Alteration:

Description

Vegetation may be altered or destroyed by offsite activities, such as construction of roads and pipelines, and by onsite activities. Most changes in vegetation that affect wildlife result from completely removing vegetation and establishing new types of vegetation that may differ from original plant communities. However, partial modification of the vegetative species composition or density can also affect wildlife.

Potential terrestrial effects

Loss or alteration of vegetation can adversely affect wildlife through destruction of food sources and cover. Wildlife that are not mobile or those species that depend on specific vegetation in the area may perish.

The larger, more mobile birds and big-game animals may be displaced to areas adjacent to the disturbed sites. If those areas are already occupied, the animals will perish. No matter how effectively displaced animals are able to utilize adjacent areas, the overall potential wildlife productivity of the area will likely be reduced. The total time that the area will be unavailable for wildlife habitation should be considered when evaluating the adverse effects.

Potential aquatic effects

Adverse effects to fish are most likely to occur when riparian vegetation is destroyed or altered. The adverse effects result from increased water temperatures, loss of organic food sources from the riparian vegetation, and an increase in sedimentation because of streambank soil instability. Removal of vegetation other than riparian types may also cause an increase in sedimentation from overland mass soil movement or surface soil erosion.

Considerations for lessening effects

- Alter vegetation only on those lands that are necessary for mining, processing, and other related operations.
- Maintain features such as:
  1. Standing dead trees that serve as nesting or resting areas for any species;
  2. Unusually tall trees that could serve as raptor nesting or perching sites;
  3. Large fallen logs that provide shelter for various species; and
  4. Isolated stands of woody vegetation that occur in flat, open areas and provide cover for ungulates.
- Use brush blades rather than dirt blades to preserve natural grass and low brush cover in areas where clearing rather than excavating is necessary for operation.
- Maintain vegetation around bodies of wate and along all perennial streams and waterway that will not be used in operating the minera development.
- Exclude habitat of federally classifie species from the area of activity. If exclusion i not needed, insure that necessary measures ar employed to protect the species.
- Revegetation of disturbed lands should b accomplished as soon as possible after opera tions have ended, including abandoned roadbed
- Special grazing systems or temporar

fencing of seeded or planted areas may be required to allow plants to become established prior to livestock or wildlife grazing.

• After the initial phases of revegetation, combinations of plants that will ultimately develop into stable and acceptable communities are established. Species are identified and planted; followup planting may be required. If revegetation by native species is desired, leave seed-source trees in place, and plant less competitive seedlings. By controlling overplanting, and planting companion species, the site can be more quickly reclaimed.

• Coordination with the vegetation specialist and soils scientist should occur when reviewing the operating plan, to choose plant species that are suitable for mine sites and that will provide the resources needed by wildlife in the area.

Additional information on vegetation can be found in the "User Guide to Vegetation"—USDA Forest Service Gen. Tech. Rep. INT-64, Nov. 1979.

2. Air Quality:

Description

Airborne contaminants in the form of gaseous emissions are caused primarily by the operation of heavy equipment and vehicles in the vicinity of the project site. Fugitive dust—another type of airborne contaminant—is caused by wind erosion of ore bodies and overburden during surface-mining activities, and by heavy equipment and transport vehicles.

Potential terrestrial effects

Vehicle exhaust contains potentially harmful gases, such as sulfur dioxide, nitrous oxide, and carbon monoxide, as well as heavy trace metals, such as lead. Heavy surface-mining activity in protected forested valleys could result in larger concentrations of harmful emissions, although the effects would be limited to areas adjacent to the mine site and access roads. Also, increased levels of lead in vegetation and wildlife have been observed in areas near heavy vehicle traffic. Plants absorb lead that accumulates on foliar surfaces. Animals may inhale or ingest the lead, or absorb it through the skin.

Fugitive dust results from various mining activities, but is greatest during the development and production phases. Dust may increase exposure to a higher than naturally occurring level of trace-element metals in local vegetation and wildlife. Actual toxicity of trace elements depends on several environmental factors. These factors include climatic conditions (particularly wind patterns); physical and chemical properties of the soil (some elements, such as arsenic, are more mobile in basic soil); species composition (some species can accumulate high levels of certain trace elements but not others); and the nature of local food webs. In areas of continual exposure, animals may suffer from disorders of the mucous membrances and pulmonary complication. (See table 10 for a listing of those trace elements that could possibly affect wildlife.)

Table 10.—*Effects of trace elements on wildlife and vegetation*

Trace element	Effect on wildlife/vegetation
Antimony	Generally considered as moderately toxic to all organisms
Arsenic	Potentially very toxic to plants and animals; actual toxicity depends on the chemical form and mode of uptake
Beryllium	Very toxic to plants and animals
Boron	Moderately toxic to plants and animals
Cadmium	Very toxic to most organisms
Chromium	Moderately toxic to plants and animals
Cobalt	Moderately to severely toxic to plants and animals
Copper	Moderately toxic to organisms at high concentrations
Fluorine	Potentially very toxic to plants and animals, particularly in the gas hydrogen fluoride
Gallium	Low order of toxicity to most organisms under natural conditions
Lead	Moderately toxic to plants and animals, although no toxicity has been reported under natural conditions
Lithium	Moderately to severely toxic to plants and animals
Mercury	Certain chemical forms can be very toxic, especially to aquatic organisms
Nickel	Less toxic to animals than to vegetation
Selenium	Animals are more susceptible than plants
Thallium	Moderately toxic to most organisms
Tin	Very toxic to plants, especially green algae; moderately toxic to mammals
Vanadium	Moderately toxic to vegetation and relatively nontoxic to animals
Zinc	Moderately toxic to vegetation and relatively nontoxic to animals
Zirconium	Moderately toxic to vegetation and of low toxicity to animals

Potential aquatic effects

Aquatic resources will not be significantly affected by airborne pollutants unless a body of water is located near the mine site. Trace elements contained in dust can accumulate in aquatic habitats. Dust from coal, bentonite, copper, oil shale, and phosphate typically contain trace elements that are associated with runoff from mine sites. All of these elements, along with uranium, radium, and thorium, and their decay products, are potentially toxic to aquatic species.

Considerations for lessening effects

Air quality at the mine site should be monitored to insure that State and Federal air quality standards are met. Air quality protection measures might include:

- Water sprinkling and oiling roads and trails; paving roads located near sensitive wildlife areas (fig. 28);
- Equipping vehicles and heavy equipment with emission control devices;
- Covering conveyor belts, especially in critical wildlife areas;
- Covering areas prone to wind erosion with mulch, straw, or matting material to prevent dust pollution;
- Water sprinkling waste rock, dumps, and tailing disposal areas.

3. Water:

Description

Decreases in surface and ground water quantity may result from use of water for mine operations, ancillary facilities, mill operations, dust control, and human use. Withdrawal of water from, or disruption of, an aquifer may lower the water table and cause localized drying of seeps and springs used by wildlife for drinking water. Such a reduction in moisture may also cause changes in vegetation composition.

Water quality considerations revolve around the fact that wildlife habitat can be polluted by toxic wastes entering ground- or surface-water supplies. Various State and Federal water-quality laws set standards for concentrations of polluting substances that result from mining, and these regulations are to be consulted.

The following discussion provides some general considerations for water supply, ground-water quality, and surface water quality.

a. Water supply

Potential terrestrial effects

Changes in water supply may force wildlife dependent on marshes or riparian areas to range farther for water, and thus encounter increased competition from animals already using the other water sources. Such competition often results in degradation of habitat.

A loss or modification of a stream and its associated vegetation can eliminate or reduce not only the resident wildlife but also migratory wildlife from vast surrounding areas, even though this wildlife may rely on the stream for a relatively short period of time. Disruption of

Figure 28. Scheduled watering of road surfaces can effectively reduce dust and prevent negative effects on vegetation.

stream zone corridors used by wildlife for food, cover, or escape, can create barriers to normal movement and reduce overall carrying capacity of the habitat.

Potential aquatic effects

The importance of water quantity changes on aquatic resources cannot be overemphasized.

Effects on aquatic resources include:

1. Impoundment, diversion, and withdrawal change natural-flow regimes, which are often detrimental to fish.

2. Any consumptive use of water by mines can not only lower streamflows, but can also reduce water supplies for reservoirs, which are common in foothill valleys.

3. Streams that have been severely dewatered are more prone to freezing (winter) and oxygen depletion (summer) with drastic effects on fish populations.

4. The operation of dewatering wells reduces the flow of groundwater into the pits by locally depressing the water table. This water table depression could, in certain cases, reduce the flow of ground water to surface waters, thus reducing streamflows or lake levels.

5. Runoff rates as well as overall changes in water supply can be affected by mining activties, producing changes in seasonal instream flow characteristics for perennial and intermittent streams.

Considerations for lessening effects

- Exclude wetlands and riparian vegetation from mineral activities. Consider use of buffer zones.
- Use water from a spring only if the spring is able to sustain the use.
- Replace the water lost as a consequence of exploration or mining operations; this must be done by the operator.
- Plan construction of mine facilities in areas other than floodplains or stream drainages where there may be risk to human life, pollution, or destruction of the existing environment caused by flood damage.
- Assure that any water appropriated for mitigation does not result in a shortage in the area from which the water is taken.
- Give priority for protection of water sources to permanent ponds or streams, then to semipermanent, seasonal, and temporary water bodies.
- Where depletions of the water supply are noted, replenish the volume as needed.
- Consider the acquisition of water rights by the mining company, with subsequent donation of the rights to the respective fish and wildlife agency, so that the water can be used to maintain or increase stream flows to previous levels.

b. Ground water quality

Description

Degradation of the chemical quality of ground water results from the leaching of ions from soil material or because of leakage from waste-management facilities; these materials can percolate down to the water table. Contaminated ground water has a minor adverse effect on wildlife and vegetation except where the water is discharged at springs, seeps, or wells, or is pumped to the surface for such uses as irrigation. Also, in areas where the water table is shallow, uptake of contaminated ground water can occur through vegetation.

Potential terrestrial effects

Contamination of ground water results from accidental leaks and spills associated with the operation of vehicles and machines, and the storage of fuels, various liquids, industrial pesticides, and herbicides. Ground water contamination can also result from pipeline breakage, holding pond failure, and leaching of salts and trace elements from overburden, waste rock, and ore storage piles. Spills and leaks tend to result in more concentrated, but widely spaced, ground water contamination, while pipeline breakage or holding pond failures can contaminate larger areas.

If shallow, contaminated ground water is taken up by plants, the plants may die or suffer considerable damage, thereby becoming unsuitable for wildlife food.

Potential aquatic effects

Contaminated ground water affects aquatic biota only in areas where this water supplements surface water supplies. Thus, the same considerations discussed in the terrestrial paragraphs apply here.

c. Surface water quality

Description

Depending upon the level of contamination, the polluted water source will either be avoided by wildlife or ingested. Ingestion may cause sickness or death, or it may have no effect on wildlife. Four sources of contaminants associated with mining have the potential for reducing surface water quality.

1. Increased sediment loads.

2. Leaching of toxic compounds or elements from exposed ore, waste rock, and overburden.

3. Introduction of excess nutrients from blasting and fertilizers.

4. Introduction of pathogens from septic systems.

In the case of surface mining and surface water quality, the potential for contamination of water supplies as a result of surface mining is great because of the prevalence of surface water in most areas. The potential for offsite contamination is also accentuated in areas where steep slopes and moderate-to-heavy rainfall serve to increase runoff unless proper measures are taken. In semiarid basins where water supplies are limited, the chance of surface water contamination is less, but the impacts on wildlife could be more severe, since available water may be limited for wildlife.

Potential terrestrial effects

The severity of the impact of reduced water quality on wildlife depends on:

1. The level of water use prior to contamination.

2. The relative abundance of alternate, undisturbed water sources.

3. The importance of the wildlife species that use the water source. For example, an endangered shore bird would be more important than an abundant and widespread songbird species.

4. The degree of contamination.

5. The extent to which the contaminants are distributed through water system networks. These effects may also be compounded by accumulation of toxic substances in aquatic biota that serve as food for terrestrial animals.

Broadcast spraying of herbicides can result in water contamination, especially if applied during windy periods, or if the herbicide is highly volatile or applied in a very fine spray. Certain herbicide chemicals, if ingested in large amounts by wildlife species at a spill site, could cross placental barriers to unborn young and result in birth defects.

Sewage sludge spills may also contaminate surface water. Without proper treatment, the sludge may contain heavy metals and pathogens that are harmful to wildlife if they enter the water supply. However, if the material is treated to remove these harmful substances, the danger is significantly reduced.

Increased levels of siltation will probably have little direct effect on the wildlife drinking it. However, the indirect influence could be much greater, because siltation reduces aquatic plant growth and production of other organisms used by wildlife for food.

Potential aquatic effects

Mining can impact aquatic life by: (1) increasing the level of suspended solids (turbidity); (2) increasing stream sedimentation, which results from erosion; (3) adding toxic substances to the water; and (4) decreasing instream flows by diversion impoundment and withdrawal.

The effects can be listed as follows:

1. High levels of suspended solids in streams can increase ventilation rates and the resulting oxygen consumption can affect fish. In addition, high suspended-solid levels decrease light penetration and reduce primary food source production.

2. Silt deposits in streams prevent water flow through interstitial areas in redds used by trout to hold eggs, which may cause eggs to die from lack of oxygen.

3. Stream sedimentation deposited in reservoirs reduces the waterholding capacity of the reservoir, also reducing available fish habitat.

4. Inorganic nutrients (fertilizers) such as nitrogen and phosphorus, stimulate algal and fish production if present in the proper quantities and lead to blooms of undesirable plankton species. Fish kills result from oxygen depletion.

5. Herbicides used during revegetation efforts can also be toxic to aquatic biota if they enter surface waters. PCB (polychlorinated biphenyls) contamination is a potential problem at mines large enough to have electrical substations. Leakage from an electrical transformer is the most likely source from which PCB's enter aquatic habitats.

6. Acid drainage from large surface mines is not normally a problem in the West. Alkaline soils and rocks generally cause any mine drainage in this region to be neutral or slightly alkaline, although some acid drainages have been associated with copper mining. However, surface mining of coal, uranium, gypsum, bentonite, oil shale, phosphate, and copper produces some specific water quality problems that are unique to the particular mining and milling process.

Considerations for lessening effects

• Emphasize measures for avoiding accidental spills and leachate contamination, rather than measures to mitigate the effects of these problems after they occur.

• Contingency plans for handling accidental spills can specify:

1. Methods for locating the source of the discharge.
2. How the discharge will be stopped.
3. How the spill will be contained.
4. Responsibility for and techniques employed in repair, cleanup, and monitoring.

• Limit use of poisonous substances, including pesticides, herbicides, or fungicides, and use only after full evaluation of possible effects and obtaining of necessary approvals.

• Become familiar with the levels of pollutants allowed in the discharge from various types of surface mines. Guidelines have been published by the U.S. Environmental Protection Agency (40 CFR 434; 40 CFR 440; 40 CFR 436).

• Keep access routes and areas of use clean of all garbage and foreign debris, and dispose of debris and garbage in an acceptable manner.

• Dispose of all solid and liquid wastes containing potential contaminants or injurious material in a manner that will not harm surface or ground water. Isolate potentially toxic leachates of minerals, overburden, waste rock, and soil storage and disposal piles to prevent contamination of the soil and ground and surface waters. Point-source discharges from mine dewatering and mineral processing waste water are controlled directly by the Federal Government. The EPA manual, "Water Quality Guidance for Mine-Related Pollution Sources (New, Current and Abandon)" (WPD 7-77-01, U.S. EPA Office of Water Planning and Standards, Washington, D.C.), lists 17 "control" principles to use in the selection and design of site-specific

Figure 29. Landfills and spoil piles displace wildlife and change their use patterns. These effects can be mitigated with sound planning and reclamation techniques.

pollution preventive measures and control practices.

Additional information on water considerations can be found in the "User Guide to Hydrology"—USDA Forest Service Gen. Tech. Rep. INT-74, Nov. 1979.

4. Topography:

Description

Topography is usually modified during a variety of mineral activities. Area surface-mining operations often generate a more moderate overall topography to facilitate revegetation. Open-pit mines are likely to require overburden disposal areas in addition to the actual pit backfill area. Overburden may be placed in valleys or natural depressions in more rugged areas, or piled against small hills or ridges on flatter terrain in intermountain basins. Recently, mine plans have attempted to blend the final contours of the reclaimed areas into the surrounding landscape.

Changes in topography that result from surface mining, although generally localized, can have major effects on the wildlife that may use the area after mining ceases (fig. 29). Topography influences microclimate and microhabitat by governing the amount of solar radiation received, and the effects of wind and humidity on wildlife.

Potential terrestrial effects

Changes in the relative amount of north- and south-facing slopes due to changes in topography have various effects on wildlife, depending on site-specific considerations. South-facing slopes in winter-range areas are important as resting and feeding areas for mule deer and elk. Reptiles may also need the warmer southern exposure to sunlight at different times of the day to regulate their body temperatures.

Natural topographic features such as caves, rough breaks, cliff faces, hummocks and hills, and valleys and canyons are extremely important to various wildlife groups, particularly during inclement winter or spring weather. Changes in microhabitat affect the nesting success of raptors, such as the golden eagle and prairie falcon, which are often highly dependent on specific microhabitat conditions that afford shading and sunning of the nest site at specific times of day.

Figure 30. Landform modifications can significantly alter natural watersheds.

otential aquatic effects

Large-scale surface-mining activities can modi-y watershed morphology, thus affecting drain-ge patterns and streamflow trends (fig. 30). his is of special concern where mining activities ccur in small branch watersheds of principal rainages. Direct destruction of important fish pawning grounds can be considered the most gnificant impact resulting from removal of atural aquatic shelters.

onsiderations for lessening effects

• Contour disturbed areas to provide favor-ole microclimatic conditions for selected wild-fe species.

• Maintain topographic features important to ildlife, particularly in areas such as shrub eppe, grasslands, and wetland riparian areas, here such features are limited. In dry, open eas where distinct topographic features are less ommon, preservation of such features may be uite important to certain wildlife species.

• In cases where preservation of onsite fea-ures is not possible, refinement of adjacent eas should be considered. These measures are scussed in chapter 7 in terms of opportunities r the wildlife resource.

Additional information on topography can be ound in "Creating Land for Tomorrow," Land-ape Architecture Technical Information Series, ol. I, No. 3, Oct. 1978.

Soils:

escription

Changes in soil materials generally have an direct impact on wildlife resources, except hen ground dwellers' habitats are destroyed. hanges in soil properties may result from andling of soils. Major considerations for wild-e include the suitability of the soils for site vegetation and prevention of soil movement to aquatic habitats (fig. 31 and 32). Also, ace requirements for soil storage may elim-ate certain wildlife habitat.

otential terrestrial effects

Soil saved for reapplication has an indirect npact on wildlife, because if insufficient soil is ved, the prospects for successful revegetation e decreased. The greatest amount of waste aterial is produced by (1) open pit operations that require the removal of thick overburden, and (2) local processing of low-grade ore. Both types of operations require large land areas for waste storage.

Changes in chemical properties of soils occurring during soil handling operations may have positive, negative, or indirect impacts on wildlife through changes in nutrient levels, pH, salinity, trace-element concentrations, and the chemical constituents of the soil solution.

Compaction of soils may occur during soil handling operations. Compaction of surface soils can decrease infiltration and increase run-off, possibly leading to a reduction in vegetation cover and an increase in sedimentation in streams. Compaction can also lead to poor soil structure. The rate of seedling emergence or the rate of root elongation can be decreased in com-pacted soils. Root penetration into soils can also be restricted if compacted layers are present. A compacted lower soil layer might also decrease leaching and cause retention of soil moisture in upper soil layers. If upper soil layers contain toxic chemical elements or compounds, revege-tation potential may be decreased, or a biomag-nification of elements harmful to wildlife may result.

Potential aquatic effects

Sodium and other salts are commonly leached from disturbed surfaces during runoff, increasing the total dissolved solids content of ground water and, ultimately, downstream waters.

Dissolved solid levels that form solutions with osmotic pressure equal to or greater than fish blood are usually harmful to freshwater fish although some species can withstand higher levels. These materials, however, help reduce the toxicity of heavy metals, such as copper and zinc.

Considerations for lessening effects

Although the primary responsibility for soil conservation rests with the soils scientist, the biologist works with the ID team to make sure wildlife values are considered in the planning process. The soil plan must be devised on a site-specific basis so that the reclaimed area can sup-port the vegetation needed by the wildlife resource. Some considerations are:

• Remove and stockpile topsoil prior to removing overburden. Locate stockpiles where

Figures 31 and 32. Soil erosion can be minimized through timely rehabilitation of the disturbed site.

they will not be covered by spoil materials. Stockpiled topsoil can be used as a surfacing material for areas where revegetation for wildlife is proposed in the reclamation plan.

• Avoid placing waste dumps in areas where topography or vegetation provide necessary habitat for the survival of resident wildlife species. During reclamation of waste dumps, provisions should be made for: proper regrading of topography; revegetating with plant species suitable to wildlife needs; and supplying offsite habitat during reclamation.

Additional information on soils can be found in the "User Guide to Soils"—USDA Forest Service Gen. Tech. Rep. INT-68, Nov. 1979.

To summarize this chapter, tables 11, 12, and 13 show the progression of mining activities leading to impacts, which ultimately affect wildlife. Table 11 shows the intensity of impacts from various activities in relation to the type of mine; table 12 relates mining activities to their expected results; table 13 shows the intensity with which the changes caused by mining are expected to affect various wildlife species.

Table 11.—*Relative intensity of impacts from various mining activities, by mine type*

	Type of mine									
Mining activity	Coal area surface	Coal underground	Coal contour surface	Uranium solution	Uranium small surface	Uranium large surface	Copper	Oil shale surface	Bentonite and gypsum	Phosphate
Exploration	2	2	3	2	2	2	2	2	2	2
Surface clearing	1	3	2	3	2	1	1	1	2	1
Construction of facilities	2	2	3	3	3	2	2	2	3	3
Excavation	1	3	2	—	3	1	1	1	2	1
Mineral removal	3	—	2	2	3	2	2	2	2	2
Mineral storage	2	2	3	3	3	2	2	2	3	2
Mineral transport	1	2	3	3	3	3	2	2	3	2
Operation of support facilities	2	2	2	2	3	1	2	1	2	2
Waste materials containment and disposal (including sediment)	2	2	2	3	3	1	1	1	3	2
Personnel transport	2	2	2	3	3	1	1	1	3	2
Work force	1	1	2	3	3	1	1	1	3	2
Reclamation	1	3	2	3	3	2	1	1	1	1

Intensity:*
1 = major, 2 = moderate, 3 = slight, — = unanticipated or insignificant.

*These numerical ratings are general in nature and the ratings for any given site or operation may differ greatly.

Table 12.—*Relative intensity of impacts resulting from various mining activities*

Result of mining activities (impacts)	Mining activities											
	Exploration	Surface clearing	Construction of facilities	Excavation	Mineral removal	Mineral storage	Mineral transport	Operation support	Waste material	Personnel transport	Associated populations	Reclamation
Human/wildlife encounters												
Harassment	3	3	1	—	2	—	3	1-2	—	2	1	2
Direct mortality												
Aquatic wildlife	3	1	2	2	—	—	2	3	1	3	2	3
Terrestrial wildlife	—	2	3	—	—	—	2	3	2-3	1-2	1	—
Habitat disturbances												
Changes in vegetation	—	1	2	—	—	—	—	3	3	—	—	1
Changes in water supply/streamflow	3	2	3	3	—	—	—	2-3	—	—	2	2
Changes in surface water quality	3	2	3	—	—	3	3	2-3	1-2	—	—	3
Changes in ground water quality	3	—	—	3	2	—	—	3	2	—	—	—
Changes in soils	—	1	2	—	—	—	—	3	3	—	—	1
Changes in topography	—	1	—	1	2	—	—	—	2	—	—	1
Generation of air-borne materials	3	1	3	2	3	2	2-3	3	2-3	—	3	3

Intensity:*

1 = major, 2 = moderate, 3 = slight, — = unanticipated or insignificant.

*These numerical ratings are general in nature and the ratings for any given site or operation may differ greatly.

Table 13.—*Relative magnitude of effects of various mining impacts on wildlife and habitat*

Result of mining activities (impacts)	Affected wildlife and habitat									
	Threatened and endangered (when present)	Migratory waterfowl	Raptors	Other birds	Ungulates	Furbearers	Small mammals	Fish/macro-invertebrates	Terrestrial vegetation	Aquatic riparian vegetation
Human/wildlife encounters										
Harassment	1	3	1	3	2	2	2	1	2	3
Direct mortality										
Aquatic wildlife	1	—	—	—	—	—	—	1	2	1
Terrestrial wildlife	1	—	2	—	1	2	3	—	2	—
Habitat disturbances										
Changes in vegetation	1	—	2	2	1	2	2	1	—	1
Changes in water supply/ streamflow	1	2	—	3	2	3	—	2	—	2
Changes in surface water quality	2	1	3	2	1	2	3	1	3	3
Changes in ground water quality	—	—	—	3	2	2	—	3	—	3
Changes in soils	—	—	—	—	—	—	3	2	1	2
Changes in topography	1	—	2	3	1	3	3	—	2	1
Generation of airborne materials	3	—	3	3	3	3	3	3	3	3

Intensity:*

1 = major, 2 = moderate, 3 = slight, — = unanticipated or insignificant.

*These numerical ratings are general in nature and the ratings for any given site or operation may differ greatly.

Chapter 7

OPPORTUNITIES FOR WILDLIFE

The Forest Service, as a public land-management agency, is charged with the responsibility of insuring that reasonable steps are taken to protect surface resources during mining and to compensate for the unavoidable adverse effects that may occur. At the same time, the Forest Service ID team, including the biologist, looks for opportunities that mining might present for wildlife. As applied here, an opportunity is a favorable condition in which to develop or enhance a resource—specifically, wildlife.

This chapter discusses some wildlife management opportunities that can arise from mineral activities. First, however, the biologist must remain aware of several "givens":

1. Mineral deposits occur only in specific locations. Although it is possible to negotiate a minor relocation of exploration activities, relocation of most activities is not possible once a deposit has been found.
2. The miner normally has certain rights that must be respected, depending on the mineral and its location.
3. The duration of some mining projects is long term, possibly continuing for several decades.
4. Substantial acreage can be involved in mineral projects.
5. Mineral projects usually involve numerous jurisdictions, which makes objective-setting and coordination more complex.
6. Mineral activities are phased and the multiple activities associated with mining can lead to multiple effects on the environment.
7. Lead time for responding to a proposed mineral project may be limited.

Because of these factors, the biologist has traditionally seen mineral development as inevitable, leading to adverse impacts that must be mitigated. While these factors cannot be ignored, mitigating actions are only one response. The biologist also may identify special opportunities for managing wildlife that arise during mineral activities. The opportunities may arise as a result of:

- Forest plan direction.
- Financing alternatives.
- New information to assist in managing wildlife, such as that available through surveys, research, or computer tools.
- Interagency coordination.
- Site-specific occurrences.

THE FOREST PLAN: A PERSPECTIVE FOR IDENTIFYING OPPORTUNITIES

The forest plan helps the biologist recognize opportunities for managing wildlife when a mineral project is proposed. It provides a broader view of wildlife goals than might be the case if the biologist analyzed the project only in relation to its effect on that one specific site. The results of a site-specific analysis are likely to show that the mineral project will adversely affect wildlife because it will change *existing* conditions on the site. The tendency may be to judge the mineral activity as undesirable because it will change the status quo. If the project is viewed in a larger context—a context provided by the forest plan—the biologist may determine that wildlife goals for the forest or region as a whole are attainable. Furthermore, ways in which the mining project presents opportunities for managing or enhancing wildlife may be identified.

As an example: Assume one wildlife objective stated in the forest plan is to increase game fish species to allow for more recreational angling. A second objective is to maintain the deer population. The area to be mined presently has no aquatic habitat but is a deer habitat. However, it is expected that mining operations will result in a large open pit and that in the process of extracting the mineral, an aquifer will be tapped, eventually filling the pit with water.

The biologist knows that if no mitigation measures are taken, this situation will result in a loss of deer habitat. However, the forest plan may reveal that the forest or region as a whole can satisfy the deer habitat objectives without this particular habitat. In this case, the biologist can look beyond the loss of deer habitat to an opportunity for creating additional fish habitat-thus meeting a second wildlife objective. What might have been seen as only an adverse effect to the deer population can now—based on the broader perspective provided by the forest plan—be viewed as an opportunity for increasing the potential to provide aquatic habitat to produce fish.

FINANCING ALTERNATIVES

In addition to monies provided through the Forest Service budget, opportunities may exist to obtain funds from other sources. For example, financing can sometimes be obtained from industry, local communities, or sportsmen's groups. These arrangements require close cooperation and advance planning between the Forest Service and the organization offering the financial assistance.

• *Private industry.* The feasibility of achieving wildlife objectives that go beyond the minimum required mitigation measures depends, partially, on the willingness of the mining company to provide financing for the work. The final plans for both financing and the construction of improvements will ultimately be determined by the mining company and the Forest Service land manager. Therefore, the biologist should provide information on opportunities for wildlife management to the land manager as early as possible in the planning process. This information should suggest a range of management opportunities and then relate each alternative to the costs and benefits expected. The land manager and industry can then negotiate reasonable requirements for specific projects.

• *Local community.* The local community may have considerable interest in a large minera project because of its wide-reaching effects, such as population growth and land-use changes Therefore, city, county, and State representa tives, as well as private individuals, may becom involved in providing additional financing fo wildlife management opportunities if they ca be shown esthetic and economic benefits tha could be realized from integrating wildlif objectives into the planning of the project.

For instance, a community may have a economy that is partly based on tourism, i particular, recreational hunting and fishin If additional tax revenue is expected fror mining or mine-related industries, the loc officials may wish to channel some of thes funds to wildlife improvement projects i order to maintain the segment of the econom that relies on hunting and fishing activitie Or, the community may want to improve th

Figure 33. Research sample plots help to identify prescriptions that are successful for revegetating most areas.

Figure 34. Joint efforts by industry and Federal and State agencies can build wildlife measures into mine plans.

ırea's wildlife habitats for sightseers who will spend money in support industries such as hotels ınd restaurants.

When such an opportunity exists, the biologist coordinates information through the appropriate State agency and the community. In this vay, funding for wildlife management opportunities may become possible through local iscal planning.

INFORMATION OPPORTUNITIES

Throughout initial planning and all phases of he mining project, various types of information re available to the biologist for exploring mangement alternatives.

By consulting research publications, the biolgist can take advantage of information already vailable. This can save time and money. Also, vailable research may suggest opportunities for ıanaging the wildlife that can be used in conınction with the mitigating procedures already lentified in research literature (fig. 33).

Where existing information is inadequate, the ıinerals project may provide an opportunity to ather new information through monitoring, dministrative studies, or research. The biologist ıay explore cooperative funding for such fforts with other Federal or State agencies ıd industry.

INTERAGENCY COORDINATION

Because wildlife habitats often span areas dministered by more than one State or Federal nd-management agency, cooperative efforts nong the involved agencies may provide opporınities for wildlife management (fig. 34). For xample, if an objective outlined in the forest an is to increase the elk population by improvg habitat, and the elk's home range falls within ıe administrative boundaries of several agenes, coordinated planning among the agencies ould allow habitat improvement to take place er the entire home range, thus benefiting the k. Furthermore, this wide-ranging effort could minish the effect of the mining project on a ırticular elk habitat.

These cooperative efforts begin by identifying mmon goals and objectives for wildlife management. Once the goals are agreed upon, the involved agencies begin planning to achieve them. During planning, agreements must be reached on: data base; estimates of habitat potential to produce wildlife objectives; judgments of expected effects from mineral activities; and efforts to deal with those effects. The agreed-upon management procedures are then collectively implemented.

Although interagency coordination can produce opportunities for wildlife, it takes careful planning and communication. Traditionally, land-management agencies have confined their efforts to areas within their administrative boundaries. Because these boundaries do not usually correspond to ecological boundaries, this practice, at times, has complicated efforts to develop common goals and objectives for broader areas of land. In addition, the distinct charters of various Federal and State wildlife agencies can make coordination complex. However, every effort should be made to coordinate objective-setting and planning with other agencies, because cooperative efforts can allow the biologist to manage the wildlife in ways that would be impossible if work were confined to National Forest System land or limited to Forest Service authorities.

SITE-SPECIFIC OPPORTUNITIES

Mining-related opportunities may exist for both terrestrial and aquatic habitat improvement. The degree of improvement is based on what is reasonable—legally, technically, and economically. The best results can be obtained by working closely with the mine operator, the local community, and the other members of the ID team. The remainder of this chapter presents some examples of opportunities for managing wildlife that may occur during mineral activities.

Surface-use changes caused by mining can result in either impacts or opportunities, or they may have no effect on wildlife. In some cases, vegetation, water supply, topography, and uses of the land can be altered to enhance habitat and benefit the wildlife resource.

Vegetation. Some wildlife species could benefit from changes in vegetation if preferred

Figure 35. Wildlife browse species are propagated in greenhouses for field planting on reclaimed sites.

Figure 36. Perch structures can be artificially placed to benefit raptors.

vegetation that was previously in short suppl is increased. Also, disturbance of a site generall results in a change in the successional stage o the vegetation community. This occurs whe vegetation, removed from a site during min development, is replaced by vegetation of a earlier successional stage. This successiona process can be somewhat altered by artificia plantings (fig. 35). Because the various stages o succession are used by different communities o wildlife species, certain species will benefit fro the change. At times, the mining developmen may result in more diversity of vegetation an support more species than did the original hab tat conditions. In effect, the reclamation effo can be used to create or improve habitat fc selected wildlife species. Often, it is impossib to protect the vegetation on a mine site durin mining activity. In such cases, the potential t improve offsite habitat to support wildli should be considered.

The principal objective of improving habit is to increase the quality and quantity of foo water, and cover on adjacent sites, thereby ir creasing wildlife habitat diversity and produ tivity on those sites. This procedure helps compensate for habitat loss in the mine area.

Improvement procedures for undisturb sites should stress the increase in the quali and quantity of food, water, and cover. Son specific methods are:

- Selective thinning of dense vegetati stands and the planting of browse and fora plant species;
- Regulation of livestock use to decrea competition with wildlife;
- Replacement of brush piles and large roc removed from the mine site in adjacent areas;
- Placement of nest boxes and perch stru tures where needed (fig. 36).
- Placement of nesting structures and roos in wet areas to increase waterfowl use.

Water supply. Mining activities have tl potential for increasing surface water quantiti through surface discharge of water previous trapped in aquifers. Keep in mind, however, th aquifer pumping is likely to reduce the surfa discharge of the aquifers in other areas. If tl discharged water is of suitable quality a reasonably constant supplies can be maintaine the additional supplies could be beneficial wildlife.

Drill holes are often used in mineral exploraion. In instances where fresh water is encounered, opportunities may exist to develop these vater sources for wildlife. Similarly, wells lrilled for potable water may be converted for vildlife use following the abandonment of nining operations. Creation of pond or lake abitats could have positive effects on wildlife, ut unless the new habitat is permanent—that is, he water supply is maintained by precipitation r runoff—long-term benefits will not be realzed (fig. 37).

In areas where precipitation exceeds evaporaon, there is a better possibility of creating ermanent aquatic habitats than in arid regions. /hen new wet areas such as ponds, lakes, or treams are planned, the following should be onsidered:

• Locate wet areas away from the influence ncluding noise and human activities) of the nining site but close enough to serve displaced ildlife populations.

• Locate wet areas so that natural topoaphic or vegetative features offer protection, articularly in the form of windbreaks or hading. Such natural features not only protect ildlife but also reduce the evaporative effects f wind and direct sunlight.

• Contour shorelines so they are easily cessible to wildlife.

• Situate wet areas where soil characteristics e conducive to maintaining bodies of standing ater for long periods of time.

• Introduce native riparian vegetation species necessary. In cases where marshes or ponds e created, aquatic vegetation attractive to igratory waterfowl can be introduced.

• Maintain water levels so that minimum uctuations occur. If water level fluctuations e substantial, it is often impossible to establish ermanent vegetation along the shoreline or to oid winterkill of fish.

• Manage the entire wet area to produce aximum water retention and minimum siltaon of the wet area. This requires permanent, ep-rooted vegetation to assure soil stability.

Water quality. Normally, prescriptions dealing th water quality are designed to prevent gradation of water that passes through the ne site.

Opportunities for improving water quality, on e other hand, must be arranged for in the operating plan and entail the improvement of certain specific water quality parameters in water that passes through the mine site. An example would be to reduce the load of suspended and dissolved solids in a stream below premining levels. For such measures to be effec-

Figure 37. The creation of aquatic habitat can enhance the diversity of wildlife species.

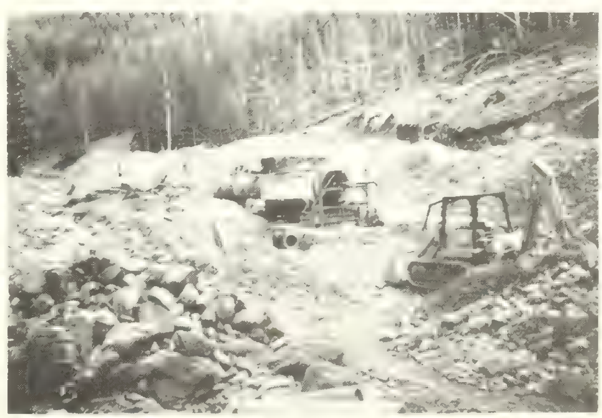


Figure 38. Placer mining can destroy stream channels and create severe sedimentation.

tive in improving aquatic habitat, parameters specified to be improved must be the ones that are already degraded.

Aquatic habitat. When streams are rerouted, the new channel may be constructed to provide better habitat than the old channel (fig. 38). To insure this, the new stream channel should contain a diverse mixture of pools, riffles, and boulder obstructions; stable banks; and a varied bottom substrate of gravel and rubble. In areas where riparian vegetation is important for maintaining cool water temperatures by shading and for increasing nutrient levels in the stream, trees can be transplanted to the new stream bank. In areas where premining alterations of the stream channel have produced poor fish habitat, a carefully constructed new section of stream channel may provide better habitat than the old channel (fig. 39 and 40). The prevention of sedimentation and silt problems is an important consideration when constructing new streams.

In some instances, ponds and lakes can be constructed off the mining site to replace those eliminated by mining. In order to provide quality fish habitat, such ponds and lakes should have sufficient water depth to prevent winterkill, properly designed spillways to handle periods of high runoff, a high-quality water supply, and areas suitable for fish spawning. In some cases, trees may be necessary to shade the water and reduce wind velocity and subsequent evaporation rates.

When stream habitat improvements are planned, cooperation between Federal and Stat biologists and the mining company is essentia to insure that improvement objectives adequate ly consider the affected wildlife species and thei habitat requirements, such as food, cover, an water needs.

Stream habitat improvements can also b classified as direct or indirect. Direct measure are those that improve the aquatic-riparia stream areas, while indirect measures are thos that improve streams through improvements t the watershed and/or floodplain within a drai age area. Stream habitat objectives can b developed to increase habitat or fisheri resources.

Stream habitat factors that can be improve include:

• Water quality (physical, biological, chen ical, radiological);

• Instream flows;

• Streambed materials (spawning gravel);

• Stream channel structure (hydrology

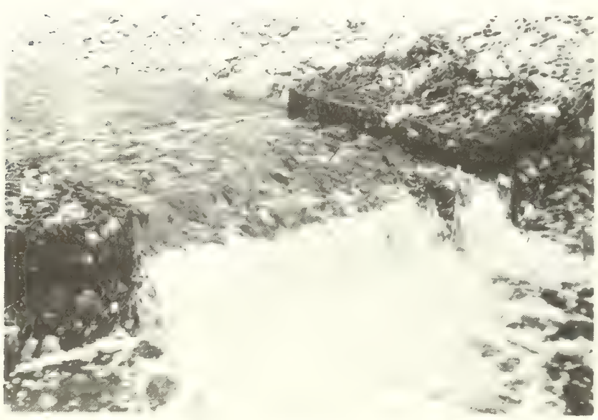
Fisheries features include:

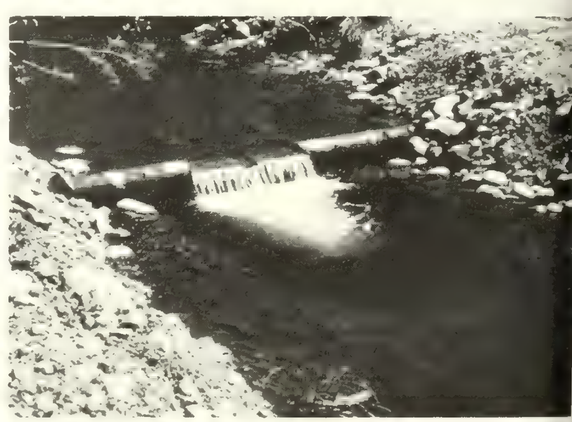
• Species composition (numbers, bioma diversity);

• Type of fishery (nongame, game, threa ened, endangered, sensitive, native, nonnative);

• Use of fishery regulations (protected, li ited, or unlimited harvest).

After the type of improvement has be identified, various methods may be used f implementation. A listing of onsite and offsi procedures follows.





Figures 39 and 40. Gabion or structures can improve fish habitats.

1. Onsite

—Streamside and/or riparian area fencing d barrier placement.

—Stream bank log cribs; bank deflectors; nk matting and mulching.

—Check dams, logs, rocks, trash catchers.

—Current deflectors.

—Fish barrier dams.

—Fishways or ladders.

—Silt check dams.

—Streambed materials.

—Spawning channels.

—Fish screening.

—Culvert and bridge design.

—Design and placement of new stream cannel.

—Streamside vegetation treatments and pntings.

—Stream bank brush shelters.

—Instream flows and water rights acquisitn (stream levels; nutrient control; pH contl; species stocking or eradication; buffer zone rintenance).

2. Offsite

—Land acquisition/withdrawal for resource ptection.

—Floodplain zoning and riparian-area value intification.

—Water rights acquisition.

—Watershed and revegetation measures.

—Mine pond location and spill contingency pn.

—Other resource use coordination.

—Fish hatcheries.

—Spring source protection.

—Early input, planning, and design into mining and forest plan.

Topography. Opportunities to improve topography may be present either offsite or onsite during mine planning and reclamation (fig. 41 and 42). Features most important to wildlife should receive priority in these operations (fig. 43 and 44).

Where the reclamation of surface-mined areas involves re-creating terrain, the biologist has an opportunity to design specific features for selected wildlife species. This would include specifying landform characteristics, such as slope, aspect, type and juxtaposition of vegetation, and water bodies.

When planning for reshaping terrain, consider:

• Providing suitable slopes for good vegetative reclamation;

• Insuring that wildlife have access to watering areas and to summer and winter range;

• Providing areas with maximum southerly exposure when the objective is to create or improve winter range conditions;

• Leaving highwalls (unexcavated faces of exposed overburden) to provide desired wildlife habitat, particularly for raptors.

Computer-assisted planning tools allow the biologist to explore opportunities for wildlife management quickly and easily. Such tools can graphically display several alternative land-

igures 41 and 42. Shaping and revegation of mine spoils can enhance aesthetics and provide wildlife forage.

Figures 43 and 44. Gravel mining operations that disrupt surface water conditions can be rehabilitated to provide an increase in wetland habitats.

forms and allow the land manager, in cooperation with industry, to choose the alternative that best achieves their mutual objectives. Thus, alternatives can be explored and evaluated prior to surface-disturbing activity.

Several methods have been developed for processing surface and subsurface data in digital form that a computer can quickly manipulate and display. By using topographic, surface, and subsurface data, the computer can depict what a proposed mining development will look like before any actual work begins on the site.

Soils. Soil improvement indirectly benefi wildlife by allowing better revegetation of mine site. A soils scientist should be consulte during the planning process to identify oppo tunities for soil improvement.

If sufficient soils are saved, properly replace and compacted, revegetation prospects are ir proved because a good growth medium f plants is provided. Soils that are susceptible erosion may need to be stabilized to ensu successful revegetation, and prevent sedime increases in aquatic habitats.

APPENDIX A

GLOSSARY

cquired lands: Lands obtained by the Govern-ent through various exchanges, purchase, or fts.

lternative: The different means by which ojectives or goals can be attained. Alternatives ed not be obvious substitutes for one another perform the same specific function.

nadromous fish: Those species of fish which ature in the sea and migrate into streams to awn. Salmon, steelhead, and shad are amples.

quifer: A geologic formation or structure that ansmits water. Aquifers are usually saturated nds, gravel, fractured rock, or cavernous rock.

seline data: Data gathered prior to mining for e purpose of outlining conditions existing on e undisturbed site. Reclamation success is easured against baseline data.

ologist: For purposes of this guide, the term ludes biologists involved in all areas of the cipline.

ota: The plants and animals of an area taken lectively.

rrying capacity: The number of animals of a en species that a habitat supports, measured the low stage of any animal population cycle.

im: The portion of mining ground held under deral and State laws by one claimant or asso-tion by virtue of one location and record.

nmon variety minerals: Minerals classified as h by statute primarily because of their wide-ead occurrence; they are disposed of by the vernment as salables. Examples are gravel, ne, sand, and pumice.

elopment: The work of preparing a proven body or reservoir for extraction and trans-ting.

Dissolved solids: The total amount of dissolved material, organic and inorganic, contained in water.

Economic feasibility: The degree of certainty or probability that a mineral commodity will be developed; factors considered are the type of mining activity and its cost in terms of time and money.

Environmental Assessment (EA): An analysis of all actions and their predictable short- and long-term environmental effects, which include physical, biological, economic, and social factors and their interactions. Also, a concise public document required by the regulations for implementing the procedural requirements of the National Environmental Policy Act of 1969 (NEPA).

Environmental Impact Statement (EIS): A document prepared by a Federal agency in which anticipated environmental effects of a planned course of action or development are evaluated, as described by the National Environmental Policy Act of 1969 (NEPA).

Erosion: The group of physical and chemical processes whereby earth or rock material is worn away, loosened, or dissolved and removed from any part of the earth's surface.

Exploration: The process of identifying and investigating mineral prospects in order to discover if a viable mineral deposit or reservoir exists.

Feasibility study: As applied to mineral activity, the feasibility study follows discovery of the mineral and is done by the operator. Its purpose is to analyze the rate of return that can be expected from the mineral development at a certain rate of production. Based on this study, the decision to develop an ore body or reservoir may be made.

Forest plan: See land-management plan.

Ground water: Water within the earth that is in the zone of saturation, where all openings in soils and rocks are filled—the upper surface of which forms the water table; water that supplies wells and springs.

Habitat: The location where an organism is generally found and where all essentials for its development and existence are present.

Interdisciplinary team (ID team): As proposed by recent Forest Service regulations, the interdisciplinary team will be comprised of Forest Service personnel who collectively represent two or more areas of specialized technical knowledge about natural resources management applicable to the area being planned. The team will consider problems collectively, rather than separate concerns along disciplinary lines. This interaction will insure systematic, integrated considerations of physical, biological, economic, and other sciences.

Land-management plan: A long-range land and resource management plan for one of the designated forest planning areas as specified in the National Forest Management Act of 1976 (NFMA), Section 6 Regulations; it outlines the most desired and alternative land uses for that site.

Land manager: A general term used to apply to the responsible official on a land unit; this could be the District Ranger, Forest Supervisor, or Regional Forester.

Leasables: Those minerals excluded from the 1872 Mining Law; they are developed under a leasing system.

Locatables: Those minerals located on public domain lands and subject to the 1872 Mining Law, as amended; such as gold, silver, and zinc.

Lode: A mineral deposit in consolidated rock, as opposed to placer deposits.

Management concern: An issue or problem requiring resolution, or a condition constraining management practices, identified by the interdisciplinary team.

Management indicator species: According to NFMA regulations, management indicator species are species identified for land-management planning purposes that include: (1) threatened and endangered plant and animal species in the area; (2) species with special habitat needs that may be influenced significantly by planned management programs; (3) species commonly hunted, fished, or trapped; and (4) species whose population changes are believed to indicate effects of management activities on other species found in the area.

Microclimate: The local climate of a given area usually characterized by considerable uniformity of climate over the site involved; the fine climatic structure of air space, which extends from the very surface of the earth to a height where the effects of the immediate character of the surface no longer can be distinguished from the general climate.

Mineral developments: This term is used in a broad sense and includes energy-related developments for such commodities as oil and gas, coal, and uranium, as well as commodities such as gold, silver, and molybdenum.

Mineral law: The collection of all laws affecting minerals and their development.

Mineral project: Specific mineral developments.

Minerals: This term is used in a broad sense and includes all substances occurring naturally with characteristics and economic uses that bring them under the jurisdiction of mineral law. The term includes oil, gas, coal, uranium, geothermal resources, and so on.

Mitigation: An action to correct or lessen the severity of an adverse effect.

Monitoring: In regard to disturbances caused by mining, the site must be carefully observed following reclamation operations to insure that reclamation goals are being met. This monitoring usually involves observations over time.

Nonpoint source pollution: Pollution whose source is general rather than specific in location

otice of intention to operate: Filed by an operor who is unsure if the proposed operations ight disturb surface resources, this notice iefly describes what the operator intends to), where and when it is to be done, routes and ethods of access to the site, and who owns and erates the property. The Forest Service will alyze the proposal within 15 days and notify e operator whether or not an operating plan necessary.

erating plan: Submitted by the operator, the erating plan outlines the steps the company ll take to develop and rehabilitate the site. e operating plan is submitted prior to startup the operations.

portunity: As used in this guide, an opportnity is a favorable condition in which to velop or make use of a resource.

erburden: Barren rock and soil overlying a neral deposit.

tent: The official document that conveys to claimant exclusive fee title to the mineral, d in most cases the surface and all resources.

cer deposits: A surficial mineral deposit f med by mechanical concentration of mineral ticles from weathered debris. The valuable neral is usually gold, tin, or some other heavy cious metal. The deposit is usually formed alluvial, marine, or other processes.

cer mining: The extraction and concentration heavy metals from placers by various methods ng running water and differential specific g vity characteristics.

tmining: The period following mineral ex-ction and initial reclamation work during ich time the operator is required to monitor success of the reclamation program and re-at problem areas.

liminary investigation: The search for reser-rs of leasable minerals, or the preliminary essment of values of reservoirs already known exist in order to identify the approximate ent of payable ground.

Production: The process of extracting and transporting mineral products from the site to a processing location or to market.

Program: As used in this guide, a program is a Forest Service administrative framework in which policy and decision-making, budgeting, on-the-ground activities, and reporting functions are accomplished.

Prospecting: A general term for a group of activities that range from regional appraisals to detailed reconnaissance; the search for new prospective deposits or reservoirs, or the preliminary assessment of the values of deposits or reservoirs already known to exist.

Public domain lands: Lands subject to appropriation as a mining claim, subject to sale, or other disposition under the general laws.

Public issue: A subject or question of widespread interest relating to management of National Forest System lands and identified through public participation.

Raptors: Carnivorous birds that have talons or claws for seizing prey.

Reclamation: Returning disturbed land to a form and productivity that will be ecologically balanced and in conformity with a predetermined land-management plan.

Rehabilitation: See reclamation.

Riparian: A broad term referring to land bordering streams, rivers, lakes, and tidewaters.

Salables: Minerals that may be acquired by purchase or free-use permit only; also called common variety minerals.

Sediment: Solid material, both mineral and organic, that is in suspension, is being transported, or has been moved from its site of origin by air, water, gravity, or ice and has come to rest on the earth's surface either above or below sea level.

Spoils: The overburden (soil and raw geologic materials) removed in gaining access to the desired mineral deposit.

Stipulations: Amendments made by the Forest Service to an operating plan for leasable minerals.

Succession: The process whereby one association of species replaces another, or the progression of vegetation over time on an area.

Surface mining: A broad term that refers to any process of removing earth, rock, and other material in order to extract the underlying mineral deposit.

Tailing pond: Area in which the waste material remaining after raw minerals or ore have been processed is contained. This term often refers to waste areas from hardrock mining, while th term "spoils" refers to wastes from open-pi mining.

Uncommon variety minerals: Minerals of th similar type as common variety or salable mi erals, but with unique properties giving the distinct and special value. If classified as u common variety, the mineral is disposed of a locatable.

Underground mining: Mining that involv extracting ore without removing the materi that lies above it, called overburden.

Ungulates: Hoofed animals.

Wildlife: For purposes of this guide, wildli consists of terrestrial and aquatic animal specie

APPENDIX B

PRESENTERS AND PARTICIPANTS

ıck Adams
ıSDA Forest Service
ildlife Management
ederal Bldg.
24 25th St.
gden, UT 84401

dwin Browning
SDA Forest Service
inerals and Geology
ederal Bldg.
24 25th St.
gden, UT 84401

ank T. Cole
S. Fish and Wildlife Service
enver Federal Center
O. Box 25486
enver, CO 80225

on Duff
SDA Forest Service
ildlife Management
ederal Bldg.
24 25th St.
gden, UT 84401

on Escano
DA Forest Service
nerals and Geology
gional Office
deral Bldg.
ssoula, MT 59807

ank Gunnell
DA Forest Service
wtooth National Forest
25 Madison Ave. East
in Falls, ID 83301

il Janik
DA Forest Service
ldlife Management
deral Bldg.
4 25th St.
den, UT 84401

Bill Johnson
USDA Forest Service
Minerals and Geology
Federal Bldg.
324 25th St.
Ogden, UT 84401

Clark Johnson
U.S. Fish and Wildlife Service
Federal Bldg., Rm. 1311
125 S. State St.
Salt Lake City, UT 84138

C. Thomas King
USDA Forest Service
Engineering
Federal Bldg.
324 25th St.
Ogden, UT 84401

John Lowe
USDA Forest Service
Wasatch National Forest
Federal Bldg., Rm. 8226
125 S. State St.
Salt Lake City, UT 84138

Steve Mealey
USDA Forest Service
Land Management Planning Unit
3825 E. Mulberry
Fort Collins, CO 80524

Stephen B. Monsen
USDA Forest Service
Intermountain Forest and
Range Experiment Station
316 E. Myrtle St.
Boise, ID 83706

John Mumma
USDA Forest Service
Wildlife Management
Federal Bldg.
324 25th St.
Ogden, UT 84401

John Potyondy
USDA Forest Service
Soil and Water Management
Federal Bldg.
324 25th St.
Ogden, UT 84401

Walt Schlumpf
USDA Forest Service
Minerals and Geology
P. O. Box 2417
Washington, DC 20013

Don Schultz
USDA Forest Service
Minerals and Geology
Federal Bldg.
324 25th St.
Ogden, UT 84401

Terry Solberg
USDA Forest Service
Minerals and Geology
P. O. Box 2417
Washington, DC 20013

APPENDIX C

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Summarizes and discusses concerns for the biologist working in minerals-area management. Topics include the biologist's role in minerals-area management; the legal framework; land-management planning; the phases of mining; guidelines for evaluating the impacts of mining on wildlife; mitigation measures; and opportunities for wildlife management.

KEYWORDS: Wildlife, mining, minerals-area management, reclamation, mitigation.

THE SEAM PROGRAM

The Surface Environment and Mining Program, known as SEAM, was established by the Forest Service to research, develop, and apply new technology to help maintain a quality environment while helping meet the Nation's mineral requirements. SEAM is a partnership of researchers, land managers, mining industries, universities, and political jurisdictions at all levels.

Although the SEAM Program was assigned to the Intermountain Station, some of its research projects were administered by the Rocky Mountain and Pacific Southwest Research Stations.

MINERAL USER GUIDES

Other User Guides for specialists involved in minerals activities are:

- User Guide to Vegetation, Gen. Tech. Rep., INT-64
- User Guide to Soils, Gen. Tech. Rep., INT-68
- User Guide to Engineering, Gen. Tech. Rep., INT-70
- User Guide to Sociology and Economics, Gen. Tech. Rep., INT-73
- User Guide to Hydrology, Gen. Tech. Rep., INT-74

To obtain copies of these guides, write: Intermountain Forest and Range Experiment Station, USDA Forest Service, 507 25th St., Ogden, UT 84401.

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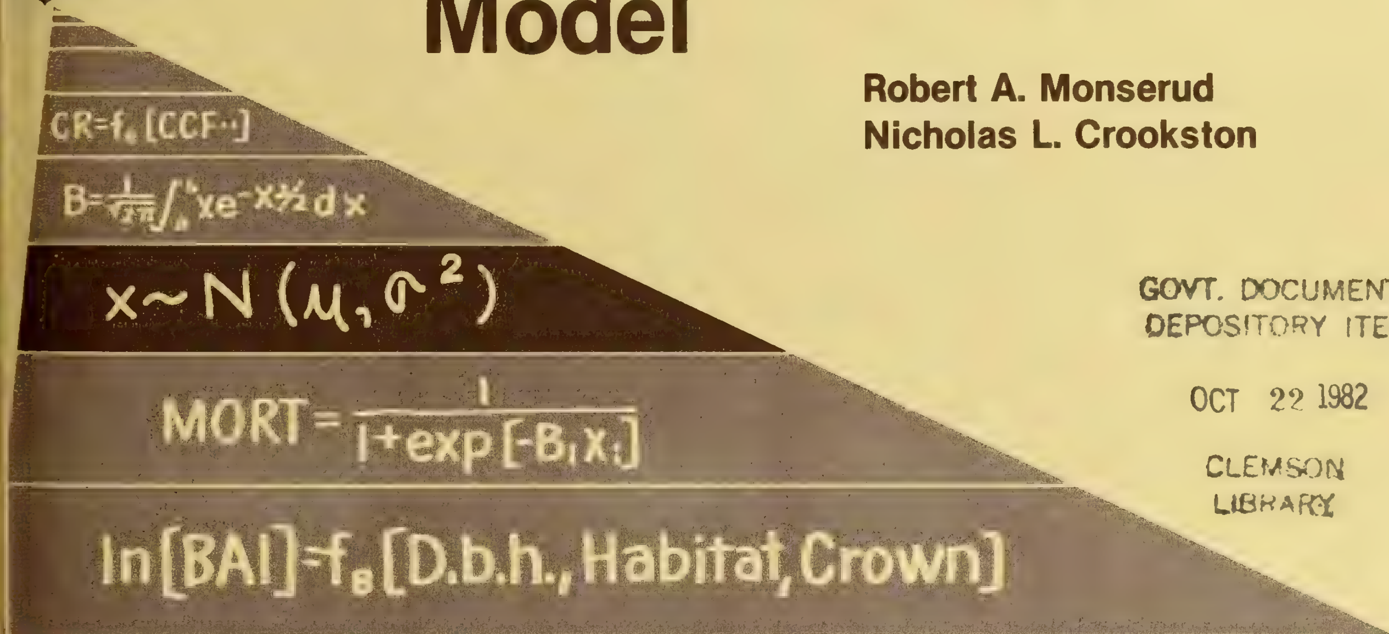
**Intermountain
Forest and Range
Experiment Station
Ogden, UT 84401**

General Technical
Report INT-127

September 1982

A User's Guide to the Combined Stand Prognosis and Douglas-fir Tussock Moth Outbreak Model

**Robert A. Monserud
Nicholas L. Crookston**



AUTHORS

ROBERT A. MONSERUD is principal mensura-
onist, Intermountain Forest and Range Experiment
ation, at the Forestry Sciences Laboratory, Moscow,
aho. Dr. Monserud is assigned to the Quantitative
nalysis of Forest Management Practices and Resources
r Planning and Control project at Moscow. He earned
B.A. degree in Mathematics in 1968 from the Univer-
y of Iowa, an M.S. degree in Forest Management in
73 and a Ph.D. in Forest Mensuration and Biometrics
1975, both from the University of Wisconsin, Mad-
on. Since joining the Intermountain Station in 1975,
s research has primarily dealt with modeling stand
namics in uneven-aged and mixed-species forests.

NICHOLAS L. CROOKSTON is research associate,
ollege of Forestry, Wildlife, and Range Sciences, at the
niversity of Idaho, Moscow. He is currently working
the Canada/U.S. Spruce Budworms Program—West
der an Intergovernmental Personnel Act agreement
tween the USDA Forest Service and the University of
aho. He received a B.S. degree in Botany in 1973
om Weber State College and an M.S. degree in Forest
sources in 1977 from the University of Idaho. His
ncipal research activities have dealt with the dynamics
the mountain pine beetle/lodgepole pine ecosystem.

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ent Station.

RESEARCH SUMMARY

This paper documents a computer model designed to simulate stand development in stands affected by the Douglas-fir tussock moth. The simulation model is actually a combination of two independently developed models: the Stand Prognosis Model and the Douglas-fir Tussock Moth Outbreak Model. This Combined Model can be used to assess the likely consequences of both silvicultural treatments and tussock moth control activities for stands in the Northern Rocky Mountains, using existing forest inventories. It can be used as a tool for long-range timber management planning because it displays the projected results of alternative strategies for the management of forests affected by the tussock moth. This integrated approach permits direct comparisons of various management and tussock moth control strategies in terms of stand volume development over time, rather than an intermediate effect such as defoliation. The flexibility of the model has also proved valuable in examining the importance and sensitivity of various assumptions in the Combined Model, and thus is useful in pointing out future research needs.

This paper covers four major areas: (1) an overview and brief discussion of the Combined Stand Prognosis and DFTM Outbreak Model is given; (2) a description of the information needed to use the Combined Model is given, which includes documentation and discussion of the input options; (3) the output and information produced by the Combined Model is discussed; and (4) numerous examples are presented that illustrate the behavior and sensitivity of the Combined Model when major input options are varied.

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Nicholas L. Crookston

INTRODUCTION

This paper reports on a computer model designed to simulate stand development in forest stands affected by the Douglas-fir tussock moth (DFTM), *Orgyia pseudotsugata* (McDunnough), which is a defoliator of true firs, *Abies* spp., and inland Douglas-fir, *Pseudotsuga menziesii* var. *glauca* (Beissn.) Franco. The simulation model is actually a combination of two independently developed models: the Stand Prognosis Model (Stage 1973; Wykoff et al. 1982), and the DFTM Outbreak Model (Overton and Colbert 1976 et seq.; Colbert et al. 1979, 1981[1]; Overton et al. 1981[2]). The Stand Prognosis Model was developed by the Intermountain Forest and Range Experiment Station in Moscow, Idaho. The DFTM Outbreak Model was developed jointly by Oregon State University and the Pacific Northwest Forest and Range Experiment Station in Corvallis, Oreg. (see Colbert [1978] for a short history of the development of the Outbreak Model). The effort that resulted in the combining of these models was sponsored by the Expanded Douglas-fir Tussock Moth Research and Development Program.

Purpose

Specifically, the purpose of this paper is fourfold:
- to provide an overview and brief discussion of the Combined Stand Prognosis and Douglas-fir Tussock Moth Outbreak Model;
- to describe the information needed to use the Combined Model, including documentation of the program options and a description of program input;
- to discuss the output and information produced by the Combined Model; and
- to provide examples that illustrate the behavior and sensitivity of the Combined Model when major input options are varied.

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[1]Colbert, J. J., W. S. Overton, and C. White. 1981. Behavior of the Douglas-fir tussock moth outbreak population model. 61 p. Manuscript in process and on file at Pac. Northwest For. and Range Exp. Stn., Corvallis, Oregon.

[2]Overton, W. S., B. E. Wickman, and R. R. Mason. 1981. Nature, organization,and content of a model for population outbreaks of the Douglas-fir tussock moth. 104 p. Manuscript in process and on file at Pac. Northwest For. and Range Exp. Stn., Corvallis, Oregon.

OVERVIEW OF THE COMBINED MODEL

The Combined Stand Prognosis/DFTM Outbreak Model can be used to assess the likely consequences of both silvicultural treatments and tussock moth control activities for stands in the Northern Rocky Mountains (northern Idaho, western Montana, eastern Washington, northeastern Oregon), using existing forest inventories. It can be used as a tool for long-range timber management planning, because it displays the projected results of alternative strategies for the management of forests affected by the tussock moth. This integrated approach permits direct comparisons of various management and tussock moth control strategies in terms of stand volume development over time, rather than an intermediate effect such as defoliation. The flexibility of the model has also proved valuable in examining the importance and sensitivity of various assumptions in the Combined Model (for example, the allocation of first instar larvae to trees of various sizes), and thus is useful in pointing out future research needs.

One of the obvious advantages of a simulation model such as this is that the user can quickly and quite cheaply compare the effectiveness of rather expensive control strategies and management alternatives. Pest control strategies available to the user include simulated application of either biological or chemical controls at various phases of the outbreak; chemical control can be applied to any instar, in any phase, at any efficacy. Silvicultural management options are available for simulating partial cuttings, thinnings, changes in species composition, and the salvage of defoliated trees. In addition, the model can be used to estimate critical insect population levels above which a given control strategy (such as applying a virus) becomes practical (Mason and Torgersen 1978). Pest monitoring can then concentrate on whether or not this critical insect level is likely to be exceeded.

Even if pest control is not anticipated, the Combined Model can be a useful tool for examining the expected long-term volume yields in the face of single or multiple outbreaks of tussock moth (see figure 1). Basing harvest schedules (e.g., Stage et al. 1980) on yields anticipated from the "no outbreak" curve in figure 1 will result in suboptimal long-range plans if the stand is subjected to one or more tussock moth outbreaks.

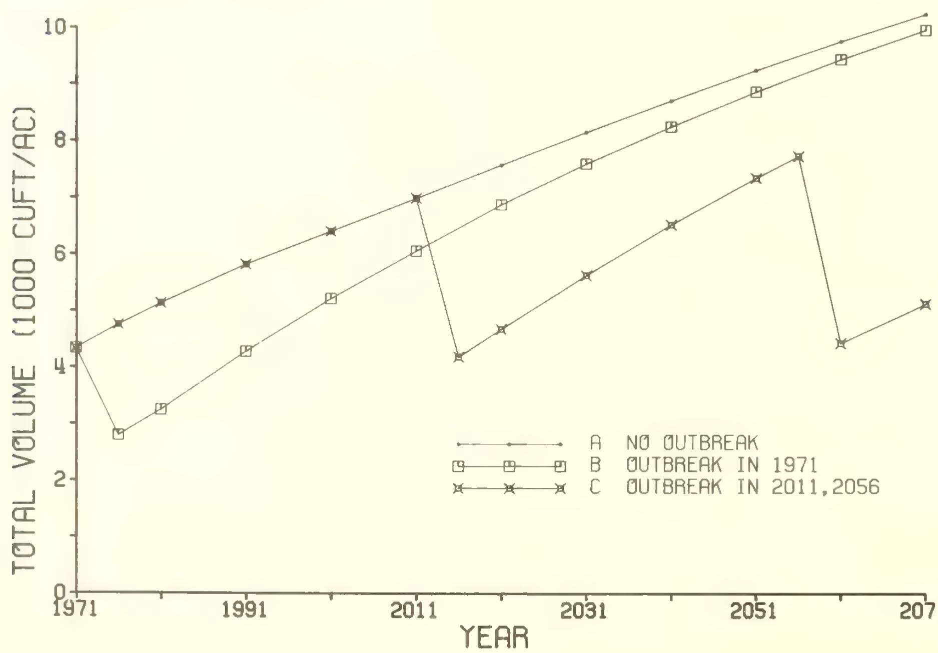

Figure 1.—An example of predicted total volume (ft^3/acre) versus time for three Douglas-fir tussock moth (DFTM) outbreak scenarios: A, no outbreak; B, outbreak in 1971 only; C, multiple outbreaks in years 2011 and 2056.

Another advantage of such a simulation model is that the user can easily see the effect of varying most assumptions that have been made in describing stand and insect conditions. Those assumptions that are supported by the least reliable information can be examined in greater detail; an ad hoc sensitivity analysis can usually be performed rather easily and should point out the assumptions that are critical, as well as those that are not. If necessary, field sampling can then be used to increase the reliability of those assumptions that appear to be either critical or weak.

The Stand Prognosis Model

Stage (1973) described a Stand Prognosis Model that has become an increasingly useful tool in examining long-term stand management alternatives (Stage et al. 1980). The Stand Prognosis program is an individual tree-based stand model designed to simulate the development of the mixed-species even- and uneven-aged stands commonly found in the Northern Rocky Mountains. The simulator consists of separate component models for tree diameter growth, height growth, crown ratio, and mortality. The projection is produced by the repeated addition of periodic increments on diameter, height, and crown ratio to the initial dimensions of the inventoried trees. Numbers of trees are reduced by periodic mortality rates. Normal period length is 10 years.

Usual input for the Prognosis program is a list of tree and stand characteristics obtained from a standard stand inventory (Stage and Alley 1972). The diameter and species of each sample tree is required, while only a subsample of total height, crown ratio, and past growth is anticipated (but not required); spatial information describing individual tree locations is not used. Site characteristics sampled include slope, aspect, elevation, habitat type, and geographic location; measures of stand density are calculated internally from the list of tree characteristics. Information describing the sampling design is also required so that the number of trees per unit area represented by each sample tree can be calculated (Stage 1978d). Stand statistics, such as basal area or volume per unit area, are then calculated by summing the corresponding tree characteristics, weighted by the number of trees represented by each tree. Thus, the Prognosis Model can be used to display relevant stand statistics versus time even though the basic unit in the model is an individual tree. A more detailed discussion of the use of the Stand Prognosis Model in timber management applications is given by Stage (1978 et seq.) and Stage et al. (1980).

The Douglas-fir Tussock Moth (DFTM) Outbreak Model

The DFTM Outbreak Model (Overton and Colbert 1976 et seq.; Colbert et al. 1979, 1981 [see footnote 1]; Overton et al. 1981 [see footnote 2]) simulates the course of events during a tussock moth outbreak on a collection of 1000 in^2 midcrown sample branches (see Mason 1970). The outbreak is assumed to be 4 years in duration, with each year corresponding to a distinct phase in the outbreak (Mason and Luck 1978). The model was calibrated using data obtained during the last (1971–74) Blue Mountains outbreak in northeastern Oregon (see Mason 1976, 1978; Wickman 1978 et seq.; Beckwith 1978). The major processes considered are insect survival, growth, and feeding and the associated host defoliation; an annual redistribution of insects between sample branches is also considered. To run the DFTM Outbreak Model, the following information is needed: insect population density, biomass of the new foliage and either percentage new foliage or biomass of the old foliage; the foliage information is needed for each of the host species considered (Douglas-fir and grand fir). Colbert and Wong (1979) have detailed the procedures for running this simulation model independently of the Stand Prognosis Model; see Colbert et al. (1979) for further documentation. Additional discussion has been provided by Overton and Colbert (1978a, b,c) and Colbert (1978). The version of the DFTM Outbreak Model (version 3.1) used as subroutines in the Combined Model discussed in this paper is the same as that described by Colbert and Wong (1979) and Colbert et al. (1979), except that the output tables have been deleted.

The Combined Model

To properly use these two rather disparate models in conjunction, an understanding of the following topics is necessary:

1. Tree defoliation effects considered by the model,
2. Foliage biomass classification model,
3. Tree class compression,
4. Methods for allocating first instar larvae to tree classes,
5. Probability of outbreak model,
6. Outbreak control and salvage options available.

Each of these topics was discussed in detail by Monserud (1978a). A brief discussion will be given here.

Tree Defoliation Effects

A tussock moth outbreak can affect normal tree development in three major ways:

1. Growth in height and diameter can be retarded,
2. Total height and volume can be reduced because of top-kill, and
3. Probability of mortality can increase.

Although there may be other effects (for example, fertilization due to rapid nutrient turnover following defoliation), only these three are simulated in this model. The research basis for the quantification of these defoliation effects is due almost entirely to the work of B. E. Wickman, at the Corvallis Forestry Sciences Laboratory (for examples, see Wickman 1978a,b; Wickman et al. 1980).

Output from the DFTM Outbreak Model consists of percentage midcrown branch defoliation in Phase II and Phase III of the outbreak for each tree or class of similar trees. Maximum defoliation on the midcrown branch is then converted to percentage tree defoliation by the function described by Overton and Colbert (1978b), which is graphed in figure 2.

Two important characteristics of this function are:

1. Percentage of tree defoliation remains essentially zero until midcrown branch defoliation exceeds 55 percent;
2. Percentage of tree defoliation then increases rapidly until complete defoliation of both branch and tree is reached.

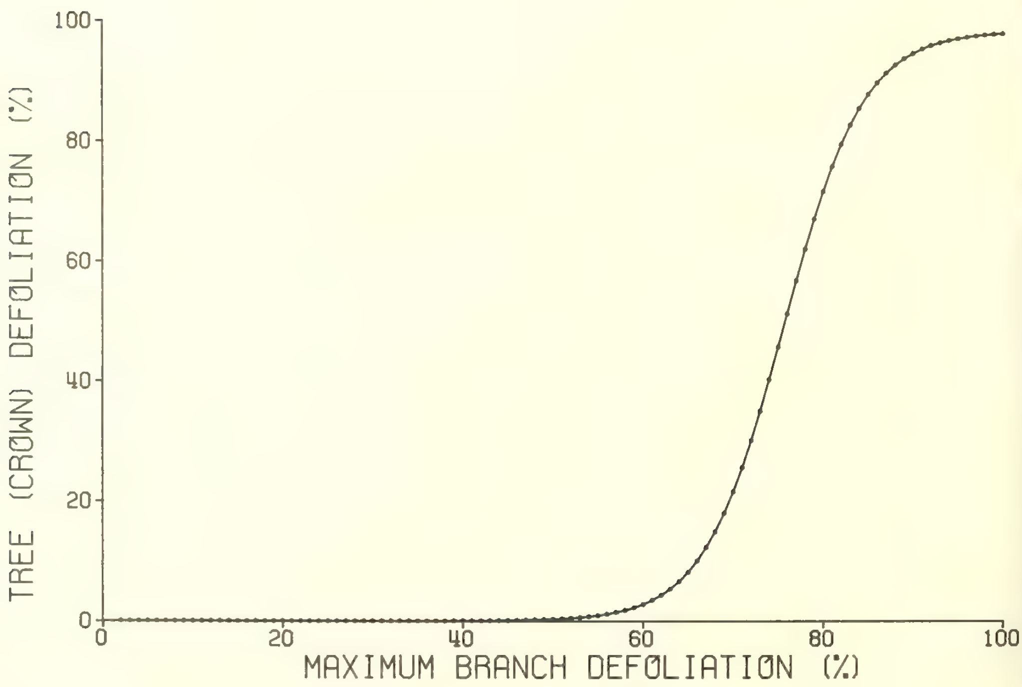

Figure 2.—Percentage tree crown defoliation versus percentage maximum midcrown sample branch defoliation (from Overton and Colbert 1978b).

It is very important to be aware of the behavior of this function when experimenting with the Combined Model, for a seemingly minor change in initial conditions could result in a dramatic change in tree defoliation if branch defoliation is between 70 and 90 percent. And any combination of control options or initial conditions that keep branch defoliation from exceeding 55 percent will produce results essentially identical to a simulation with no tussock moth outbreak at all.

Percentage of tree defoliation for a particular tree or class of similar trees is then used to index the table of defoliation effects (see Table 11-2 on p. 226 of Colbert and Campbell 1979, and discussion by Monserud 1978a, p. 65–66); note that the sampling basis for the defoliation effects is approximately 5 years (Wickman 1978a). This table contains the following species-specific information for seven tree defoliation classes:

1. Probability of direct mortality caused by tussock moth;
2. Probability of secondary and background mortality,
3. Probability of top-kill occurring on surviving trees for each of five top-kill classes;
4. Percentage of diameter and height growth reduction.

With the exception of calculating volume loss due to top-kill (Monserud 1980, 1981) the modification of tree characteristics resulting from defoliation is straightforward.

Foliage Biomass

The DFTM Outbreak Model of Overton and Colbert (1976) simulates the course of events during an outbreak on a collection of midcrown sample branches of 1000-in^2, as described by Mason (1970). The sample branch has only three essential characteristics: host species (Douglas-fir or grand fir), percentage new foliage, and total foliage biomass. Since the basic unit in the Stand Prognosis Model is a tree, and the basic unit in the Outbreak Model is a branch, a linkage between these units is needed to combine the two models. Species-specific equations for predicting foliage biomass characteristics of the sample branch, from tree and stand information available to the stand model, facilitate this linkage. Available equations were developed by C. R. Hatch at the University of Idaho (Hatch and Mika 1978; Monserud 1978a, p. 49–56). Unfortunately, the data base supporting these equations is quite limited, and should be improved. By sampling for the mean and standard deviation of the necessary foliage characteristics, the user is likely to increase the accuracy of the resulting simulations.

Tree Class Compression

The current version of the Stand Prognosis Model (Inland Empire version 4.0, as documented by Wykoff et al. 1982) can handle up to 1,350 individual tree records. Even when the number of records in a sample stand is small, the record tripling logic described by Stage (1973, p. 12–13) will usually result in several hundred tree records being projected. The DFTM Outbreak Model, however, only views trees in two dimensions (foliage biomass and percent new foliage) for each host species. Considerable computer time can therefore be saved by "compressing" trees with similar foliage biomass characteristics into the same tree class before the Outbreak Model is called (see discussion preceding the NUMCLASS keyword in a following section). Each "tree class" represents one or more tree records in the stand model and is represented by one midcrown sample branch (Mason 1970) in the Outbreak Model. The current version of the Combined Stand Prognosis and DFTM Outbreak Model allows for a maximum of 100 tree classes; this arbitrary limit appears to provide quite adequate resolution for simulating defoliation effects.

Allocation of First Instar Larvae

In addition to the foliage biomass information, the Tussock Moth Outbreak Model requires the specification of the number of established first instar larvae for each tree class at the start of an outbreak (Phase I). A tree class is simply a class or group of similar trees represented by a single midcrown sample branch. Note that "first instar larvae" in this paper should be considered synonymous with "viable eggs" in earlier papers (e.g., Monserud 1978a,b).

Two methods—assumptions, actually—are currently available for allocating levels of first instar larvae to the tree classes: the first is random and the second is deterministic. These methods allow for examining the various assumptions concerning the between-tree distribution of larvae in a stand.

With the random method, the number of larvae assigned to a particular tree class is drawn from a random normal distribution with specified mean and standard deviation. This option is quite useful when a sample of early instar larvae is available for a stand, assuming that no relationship can be found between larval density and observable tree characteristics. The random method also contains a feature that allows the user to vary the mean larval density if multiple outbreaks are being simulated.

The deterministic allocation method assigns three specified larval levels or densities to each ordered third of the tree classes, after the tree classes have been sorted by average diameter; the first tree class to have larvae assigned to it has the largest average diameter.

Wickman (1978a) reported on the distribution of mortality by diameter class in the last Blue Mountains outbreak. Either of these larval allocation assumptions could be used to mimic the evenly distributed pattern (with respect to diameter) of mortality for grand fir. The deterministic assumption, however, would be most amenable to reproducing the distribution of mortality reported for Douglas-fir, which was more concentrated in smaller diameter trees.

The actual levels of larvae specified with any of these options should be based on the most reliable estimates available, for this is the most important variable in the outbreak model. The choice of the assumption or method most appropriate for a particular situation should—if possible—be determined by analyzing tussock moth inventory data in relation to tree diameter or size. If this is not possible, we recommend using the random allocation method.

Probability of Outbreak

The DFTM Outbreak Model is just that—it simulates the course of events during a tussock moth outbreak. It was not designed to model population dynamics when the tussock moth is not at outbreak levels. Thus, the crucial decision of whether or not to invoke an outbreak must be made before the DFTM Outbreak Model is called. This forces consideration of the probability of an outbreak occurring in a given stand, in a given year.

The salient features of past outbreak patterns (Stage 1978a) are: outbreaks appear to be synchronized over large areas; intervals between outbreaks are usually at least 8 years; some stands are involved in repeated outbreaks, while others are involved only once; and not all the stands with similar conditions and histories are involved in a given outbreak.

These four features can be represented by the two-step process described by Stage (1978a). First, a sequence of dates is stochastically determined that represent the times when large-area outbreaks are to be simulated. This sequence represents the temporal probability of outbreak. Second, the relative probability with which a stand of particular attributes can be expected to show defoliation at the time specified by step one is then determined; this is the spatial probability of outbreak, conditional on the temporal probability of outbreak. The model used to predict the spatial probability of outbreak was developed by Heller et al. (1977), and uses both physiographic variables (slope, aspect, elevation, topographic position) and stand variables (crown closure, percent host species, average crown diameter). A similar outbreak model has recently been developed for the Palouse Ranger District (Clearwater National Forest) northeast of Moscow by P. B. Mika and J. Moore (personal communication 1979; see Stoszek et al. 1981 for a related analysis) at the University of Idaho. Mika and Moore's model was developed from data collected on ground plots, whereas data used by Heller et al. (1977) was obtained from aerial photographs in the Blue Mountains and Colville areas. The long-term accuracy of these models for predicting the conditional probability that a given stand will be involved in a regional outbreak is unfortunately unknown, for they are developed from data collected in only one regional outbreak (1971–74). Such models are also likely to be conditional on the specific (and unquantified) climatic factors associated with the 1971–74 outbreak.

The use of the probability-of-outbreak model is not a necessary feature of the combined system; an option is available for simulating any predetermined sequence of outbreaks. This option is quite useful for making retrospective comparisons of management alternatives when a stand's outbreak history is known.

Outbreak Control and Stand Management Options

The DFTM Outbreak Model can be used to simulate a number of control options—biological as well as chemical—by altering mortality rates at specific occasions in the outbreak. In the combined model, a simulated chemical control can be applied to any instar in any phase of the outbreak with any efficacy. Biological control options are available for applying nuclear polyhedrosis virus (NPV) in either Phase II or Phase III of the outbreak.

A wide variety of silvicultural options are also available in the Stand Prognosis Model. Thinning is simulated by reducing the number of trees per acre represented by the tree records until a user-specified thinning target is reached. The thinning target can be specified as:

a residual number of trees per acre;

a residual basal area per acre;

a segment of the diameter distribution;

a percentage of full stocking;

a prescription where specific tree records are coded for cutting.

The first three targets can be reached by thinning either from above or below. These thinning options can be implemented in any cycle of a simulation. Options are also available for specifying species preferences for harvesting that would allow for selectively removing host species. Use of the thinning options is discussed by Wykoff et al. (1982).

An additional harvesting option is also available in the Combined Model: a salvage thinning operation immediately following the outbreak can be requested. All host trees that have been defoliated more than a (user-supplied) minimum percentage tree defoliation will be salvaged. Thus some of the volume that normally would be lost due to tussock moth can be recovered. Of course, this will usually result in harvesting additional trees that are partially defoliated, but not killed—as happened in the last Blue Mountains outbreak.

DOCUMENTATION OF INPUT OPTIONS

The Combined Stand Prognosis/DFTM Outbreak Model utilizes a **keyword** system for specifying program options. The keywords are intended to simplify the process of specifying the various features of the model that will be implemented in a given simulation or run. The keyword system is analogous to a high level (albeit simple) computer language in which each instruction or keyword is translated into a number of complicated instructions. To invoke a particular option, the user simply inserts a short keyword in the runstream that is sent to the computer. For example, the keyword NPV2 specifies the application of **n**uclear **p**olyhedrosis **v**irus in Phase II (**2**) of an outbreak; although four separate tussock moth mortality rates need to be altered to simulate this option, these rates do not need to be provided by the user. The user is required to supply much less information to effect the desired result. Furthermore, the order that the information or keywords are submitted is usually not important; of course there are exceptions to this rule (for example, the DFTM keyword must precede all other tussock moth keywords). This keyword system is used extensively in the Combined Model, and has greatly simplified the process of preparing a simulation.

An additional simplifying feature of the keyword system is that default values exist for almost all keywords. Only keywords for nonstandard options need be specified, and the only numeric (parameter) values necessary on such keyword cards are those that differ from the default parameter values. In addition, all options and parameter values are reset to the default values after projecting a given stand in a multi-stand simulation.

Rules for coding keywords:

1. All keywords start in column 1 of the keyword card or record.
2. Numerical values (termed "parameters") needed to implement an option are contained in seven numeric "fields" that are each 10 columns wide, beginning in column 11. A decimal point should be punched for all numeric values that are not integers, and integer values should either be right-justified in the numeric field or followed by a decimal point. If a decimal point is provided, the actual location of the numeric value within the 10 column wide field is unimportant.
3. Blanks that are coded in the numeric fields are not treated as zeroes. If a blank field is found, the default value will be used. If zeroes are to be specified, they must be punched. Thus, only the numeric values that are different from the default parameter values need be specified (in the appropriate field, of course).
4. When two or more conflicting options are encountered, the last one specified will be used.
5. The first tussock moth keyword must be DFTM, and the last tussock moth keyword must be END.

This paper documents only those keywords used to implement the various features of the tussock moth portion of the Combined Stand Prognosis/DFTM Outbreak Model. Documentation for the keywords used by the Stand Prognosis Model is provided by Wykoff et al. (1982). Although these additional keywords are necessary to run the Combined Model, they are not listed here to avoid duplication with Wykoff et al. (1982).

Keywords will be grouped into the following five categories in the subsequent sections: program execution options, outbreak timing options, outbreak initial conditions options, tree class compression and redistribution options, and outbreak control options. Each section will contain a definition and short description of relevant keywords. Most sections will end with examples illustrating the use of keywords to simulate specific situations.

Program Execution Options

The keywords for controlling program execution options serve four general functions. The DFTM and END keywords signal the Stand Prognosis Model that tussock moth keywords will follow and have ended, respectively. NODFRUN and NOGFRUN can be used to exclude either Douglas-fir or grand fir as a host for tussock moth. DEBUG, DEBUTREE, PUNCH, REPORT, and DATELIST provide supplemental (and occasionally voluminous) output useful for examining the program's behavior in greater detail than that afforded by the usual output. And RANNSEED allows the user to choose a different random number sequence in any of the routines related to tussock moth. With this last option, a user can assess the magnitude of the variability associated with the stochastic components of the Combined Model. We anticipate that the only keywords in this section that most users will need to use are DFTM, END, and RANNSEED.

Keyword	**Keyword Description**
DFTM	Signal the Stand Prognosis Model that tussock moth keywords follow; use of this keyword is *mandatory.*
END	Signal the Combined Model that the preceding group of tussock moth keywords has ended. Any number of groups of tussock moth keywords can be used, provided each group begins with the DFTM keyword and ends with the END keyword. Use of this keyword is *mandatory.*
NODFRUN and NOGFRUN	These keywords inhibit the DFTM Outbreak Model from simulating the activity of tussock moth on Douglas-fir (NODFRUN) and/or grand fir (NOGFRUN).

DEBUG A large amount of intermediate output detailing the operation of the Combined Model will be printed. This and the following option should rarely be needed by the normal user.

DEBUTREE Long tables of intermediate values associated with individual tree records will be printed.

PUNCH The input values and parameter arrays needed by the DFTM Outbreak Model as well as the defoliation levels by tree class, species average, and stand average are written in card image format to a separate output unit.

Field 1: The FORTRAN data set reference number where the supplemental output is written; there is no default.The user must specify a valid number and the corresponding job control statement.

REPORT Control the amount of tussock moth output generated by the Combined Model; default is 2.

Field 1: The report level, where:
0 = no tussock moth output will be generated;
1 = only the DFTM Outbreak Summary Table will be printed;
2 = All normal tussock moth output tables will be printed (described in the INFORMATION PRODUCED section).

DATELIST All tussock moth subprograms (i.e., subroutines and functions) and common blocks are listed with the date each was most recently revised.

RANNSEED The pseudorandom number generator (Marsaglia and Bray 1968) used by the Combined Model has three seeds. These seeds initialize the random number generator, and are set at the beginning of each simulation. As a result, the random numbers will be generated in the same order each time a runstream is submitted. Consequently, identical projections of a single stand made in separate runstreams will have identical results. You can introduce some random variation by replacing one or more of the seeds. Since the new seeds should be odd integers, 1 will be added to any even numbers that are used to reseed the random number generator. Note that this random number generator is used only by the tussock moth related subroutines in the Combined Model; the Stand Prognosis Model has a separate, but identical, random number generator that is unaffected by this reseeding.

Field 1: First seed; the default is 1409859205.

Field 2: Second seed; the default is 402656419.

Field 3: Third seed; the default is −328609067.

Outbreak Timing Options

As discussed in the "Probability of Outbreak" section, specifying the time periods that the DFTM Outbreak Model is to be called is a two-step process. The first step schedules the occurrence of regional tussock moth outbreaks. This step can be handled in two different ways: manually (deterministically), using the MANSCHED keyword, or randomly, using the RANSCHED keyword. The second step selects which regional outbreaks will include the subject stand. The MANSTART keyword specifies that the subject stand will be included in all regional outbreaks; the RANSTART keyword makes this determination random, conditional upon the stand's probability of outbreak. The PROBMETH keyword specifies

the method for calculating the stand's conditional probability of outbreak. The TOPO and ASHDEPTH keywords provide information on topographic position and ash depth, required by some of the options available with the PROBMETH keyword.

MANSCHED — Manually specify either the calendar year or the cycle number in which a regional outbreak will occur; the default is for *NO* regional outbreaks to occur. If more than one regional outbreak is to be scheduled, use additional MANSCHED keywords.

Field 1: Either the year or the cycle number in which a regional outbreak will occur; default is for no regional outbreak to occur. NOTE: The Combined Model assumes that a number in Field 1 is a cycle number if it is less than or equal to 40—the maximum number of cycles (i.e., growth projection periods) allowed by the Stand Prognosis Model.

RANSCHED — Invoke the random automatic scheduling process which will stochastically generate a list of regional outbreaks which occur during the simulation period (see Stage 1978a). This is done by drawing from a random Bernoulli process with a specific minimum waiting time (Field 1) and a specific event probability (Field 2); the process begins with the year of the last regional outbreak (Field 3).

Field 1: The minimum waiting time between regional outbreaks; default is 30 years.

Field 2: The event probability used in the random Bernoulli process; default is 0.1. This is essentially the annual probability of a regional outbreak given that the minimum waiting time since the last outbreak has been exceeded. Note that the expected value of the time (T) between outbreaks is $T = M + (1/P) - 1$, where M is the minimum waiting time (Field 1) and P is the event probability (Field 2).

Field 3: The calendar year of the last regional outbreak; default is year 1492.

MANSTART — Specify that the DFTM Outbreak Model will be called whenever a regional outbreak is scheduled. MANSTART is the default "start" option.

RANSTART — Stochastically determine if the subject stand will be included in the regional outbreak. This is done by calculating a conditional probability (determined by the method specified in Field 1 of the PROBMETH keyword), that the subject stand will be infested by tussock moth, given that there is a regional outbreak. If this conditional probability is greater than a uniform random number between 0 and 1, then the regional outbreak includes the subject stand.

PROBMETH — Select a method for calculating the conditional probability that the subject stand will be included in a regional outbreak. This keyword is normally used in conjunction with the RANSTART keyword. If this keyword is used with the MANSTART keyword, the conditional probability of outbreak calculations will be made and printed in the "DFTM Outbreak Summary Table" (discussed in a later section), but will otherwise be ignored by the program.

Field 1: The conditional probability calculation method (default is method 1), where:

1 = Use the model developed by Heller et al. (1977), which is a

function of elevation, slope, aspect, topographic position, stand closure, proportion of stand in host, and average crown width. The last of these three variables are calculated as functions of crown competition factor. This model was calibrated using aerial photo interpretation data from the Blue Mountains of northeastern Oregon. See the TOPO keyword below for details concerning the topographic position specification.

2 = Use a model developed by Mika and Moore (personal communication, 1979) which is a function of topographic position (see TOPO), ash depth in inches (see ASHDEPTH), total basal area, and proportion of the stand in grand fir. This model was calibrated using data collected from the Palouse Ranger District of the Clearwater National Forest, northern Idaho.

3 = Use a model similar to 2 above, except that ash depth is not used. This model was developed using the same data used to develop model 2.

Field 2: The conditional probability scaling factor.[3] The default scaling factor is 1.0; a value of 0.5 would reduce the calculated conditional probability by half, and a value of 2.0 would double the calculated value.

TOPO

This keyword is used in conjunction with the PROBMETH keyword to enter the numeric code specifying the topographic position of the stand. When the conditional probability calculation method (Field 1 of the PROBMETH keyword) is 1, TOPO codes are:

1 = ridgetop
2 = sidehill
3 = bottom.

When the conditional probability calculation method is 2 or 3 (in Field 1 of the PROBMETH keyword), TOPO codes are:

1 = ridgetop or upper slope
2 = midslope or lower slope.

Field 1: Topographic position code (default is 1).

ASHDEPTH

When the conditional probability calculation method (specified in Field 1 of the PROBMETH keyword) is 2, the soil ash (loess) depth is needed to calculate the conditional probability that the subject stand will be involved in a regional outbreak.

Field 1: The ash depth in inches (default is 15.93).

The following two examples illustrate the use of several of the preceding keywords in tailoring a simulation to specific situations.

[3]Note that the available conditional probability of outbreak models were all developed using data describing stand conditions in only one regional outbreak—the 1971-74 outbreak. Such models predict conditional probability of outbreak only as a function of site and stand characteristics, even though the dependent variable is also conditional on a number of unobserved factors, such as climate and weather. The fact that such climatic factors are very difficult to quantify and relate to specific outbreak histories (Mason and Luck 1978) does not make the probability of stand outbreak models any less conditional on the specific climatic factors associated with (and perhaps peculiar to) the 1971-74 outbreak. The potential for such models to overestimate the probability of a stand being involved in future outbreaks is large, in our opinion.

Example 1.

You desire to simulate the following conditions. You hypothesize that the annual probability of a regional tussock moth outbreak occurring is 0.1, given that at least 20 years has elapsed since the last tussock moth outbreak (which occurred in 1971). You want to use Heller's model to stochastically determine whether or not there will actually be an outbreak in the sample stand if there is a regional outbreak. You believe, however, that Heller's model overestimates the conditional probability of stand outbreak by a factor of 4. Furthermore, you are curious to see just what the "large amount of intermediate output detailing the operation of the Combined Model" looks like. Finally, you would like to use the default values of all other keywords. The following group of tussock moth keywords will accomplish this:

```
DFTM
RANSCHED        20.       0.1       1971.
RANSTART
PROBMETH         1.       0.25
DEBUG
END
```

Example 2.

You would like to see how the results from the simulation described in example 1 are changed when you reseed the random number generator. You are also no longer curious to see the additional output DEBUG produces. Adding the RANNSEED keyword with any three odd numbers (and deleting DEBUG) will accomplish this:

```
DFTM
RANSCHED        20.       0.1       1971.
RANSTART
PROBMETH         1.       0.25
RANNSEED        13.       571.      14327.
END
```

Outbreak Initial Conditions

The DFTM Outbreak Model requires information describing tussock moth population levels and foliage biomass at the start of an outbreak (Phase I), on a 1000-in^2 midcrown sample branch basis. Recall that this sample branch represents a group or class of trees in the outbreak model. Larval density at the start of every outbreak can be assigned either randomly (RANLARVA) or deterministically (DETLARVA) for each host species; the same method must be used for both host species. The BIOMASS keyword specifies how foliage biomass is to be determined. And if sample-based estimates of the mean and standard deviation of the foliage distribution are available, they can be incorporated via the DFBIOMAS and GFBIOMAS keywords.

RANLARVA — Randomly allocate first instar larvae to the tree classes at the start of every outbreak. Note that this is the default larval allocation method. The host species is specified in Field 1; larval density is drawn from a normal distribution with mean specified in Field 2 and standard deviation specified in Field 3. The mean larval density (Field 2) may vary from outbreak to outbreak if the between-outbreak standard deviation (Field 4) is positive.

Field 1: Host species:
1 = Douglas-fir, and 2 = grand fir.

Field 2: The average number of first instar larvae per midcrown sample branch for the host species specified in Field 1; defaults are 9 and 11 larvae per sample branch for Douglas-fir and grand fir, respectively.

Field 3: The within-outbreak standard deviation of first instar larvae; default is 2.0 larvae for both host species.

Field 4: The between-outbreak standard deviation of first instar larvae; default is 0.0 for both host species. If this parameter is positive, the average larval density for the proper host species will be randomly chosen at the start of every outbreak by drawing from a normal distribution with mean specified in Field 2 and standard deviation specified in Field 4. Larvae will then be allocated to individual tree classes by randomly drawing from a normal distribution with this randomly chosen mean, and standard deviation specified in Field 3. This feature is best suited for use with the keywords that produce multiple outbreaks (primarily RANSCHED).

DETLARVA Deterministically assign different levels or densities of first instar larvae to each third of the tree classes, after sorting the tree classes by average diameter (in descending order).

Field 1: Host species:
1 = Douglas-fir, and 2 = grand fir.

Field 2: The number of larvae assigned to the largest third of the tree classes; defaults are 11 and 15 for Douglas-fir and grand fir, respectively.

Field 3: The number of larvae assigned to the middle third of the tree classes; defaults are 9 and 10 for Douglas-fir and grand fir, respectively.

Field 4: The number of larvae assigned to the smallest third of the tree classes; defaults are 7 and 5 for Douglas-fir and grand fir, respectively.

BIOMASS Specify the method for calculating foliage biomass (in grams) and percentage new foliage on the 1000-in^2 midcrown sample branches; default is method 4.

Field 1: The calculation methods are:

1 = The foliage biomass and percentage new foliage values will be randomly drawn from a normal distribution. The default mean and standard deviation of the foliage biomass distribution is 215g and 64g for Douglas-fir and 227g and 64g for grand fir, respectively (from Hatch and Mika 1978, p. 16). The default mean and standard deviation of the percentage new foliage distribution is 27 and 13 for Douglas-fir, and 35 and 7 for grand fir, respectively (from Hatch and Mika 1978, p. 21). These defaults can be replaced by using the DFBIOMAS and GFBIOMAS keywords.

2 = The species-specific equations developed by Hatch and Mika (1978) are used deterministically to predict the percentage new foliage and foliage biomass from tree and site variables. Because the equations behave poorly, Monserud (1978a) recommended that this option not be used.

3 = Species-specific equations developed by C. R. Hatch, University of Idaho (see Monserud 1978a, p. 55) will be used to deterministically predict percentage new foliage and foliage biomass; the only independent variable is basal area percentile.

4 = Same as method 3, but with a random normal error (with mean = 0) added to each prediction. The standard deviation of this random error distribution equals the standard error of the regression fit described in method 3. For foliage biomass, the standard deviation is 57g for Douglas-fir and 58g for grand fir; for percentage new foliage, the standard deviation is 11 for Douglas-fir and 7 for grand fir (see Monserud 1978a, p. 55).

DFBIOMAS — Used to replace the default parameter values determining Douglas-fir sample branch foliage biomass, when method 1 is specified on the BIOMASS keyword; foliage biomass and percentage new foliage will be randomly drawn from a normal distribution with mean and standard deviation specified by Fields 1 through 4:

Field 1: The mean of the foliage biomass distribution for Douglas-fir; default is 214g.

Field 2: The standard deviation of the foliage biomass distribution for Douglas-fir; default is 64g.

Field 3: The mean of the percentage new foliage distribution for Douglas-fir; default is 27.

Field 4: The standard deviation of the percentage new foliage distribution for Douglas-fir; default is 13.

GFBIOMAS — Same as DFBIOMAS, but for grand fir; used in conjunction with BIOMASS method 1.

Field 1: The mean of the foliage biomass distribution for grand fir; default is 227g.

Field 2: The standard deviation of the foliage biomass distribution for grand fir; default is 64g.

Field 3: The mean of the percentage new foliage distribution for grand fir; default is 35.

Field 4: The standard deviation of the percentage new foliage distribution for grand fir; default is 07.

Example 3.

You would like to make a projection with only one DFTM outbreak. You also want this outbreak simulated in year 1971 (which happens to be when the first cycle of the projection begins). You have estimated that the outbreak probably began in this stand with an average of nine first instar larvae per 1000-in^2 midcrown sample branch on Douglas-fir, and 12 larvae per sample branch on grand fir; your best estimate of the standard deviation is approximately four larvae per sample branch on either host species. You prefer to use biomass method 1 rather than the default method (4). The following keywords will accomplish this (note that MANSTART is supplied by default):

```
DFTM
MANSCHED      1.
RANLARVA      1.      9.      4.
RANLARVA      2.     12.      4.
BIOMASS       1.
END
```

Example 4.

You want to modify the simulation in example 3 to include multiple outbreaks that are stochastically determined but occur approximately every 45 years, with a minimum waiting time of 36 years (note that these assumptions imply an annual probability of regional outbreak of 0.1). You have very little information on how outbreak severity varies in the long run, but you are sure that it is not constant; thus you assume that the between-outbreak standard deviation of larval density is approximately 5 larvae for both host species. You would also like to modify your foliage biomass assumptions as follows: Mean foliage biomass of a 1000-in^2 midcrown sample branch is 100g and 200g for Douglas-fir and grand fir, respectively, while mean percentage new foliage is 20 percent for Douglas-fir and 30 percent for grand fir; you have no information that warrants replacing the default foliage standard deviations. The following keywords will mimic these assumptions:

DFTM				
RANSTART				
RANSCHED	36.	0.1	1971.	
RANLARVA	1.	9.	4.	5.
RANLARVA	2.	12.	4.	5.
BIOMASS	1.			
DFBIOMAS	100.		20.	
GFBIOMAS	200.		30.	
END				

Tree Class Compression and Redistribution Options

Before the DFTM Outbreak Model is called, the list of up to 1,350 tree records carried by the Stand Prognosis Model is compressed into a maximum of 100 groups or classes of trees (see NUMCLASS and WEIGHT). The purpose of this compression is to save computer time, by combining trees that are similar (as far as the DFTM Outbreak Model is concerned) into the same tree class. Once these tree classes have been created, the rate at which insects are assumed to annually redistribute between tree classes can also be specified (see REDIST). It is anticipated that very few users will have need of the keywords discussed in this section (viz., NUMCLASS, WEIGHT, REDIST). The default values should be adequate for most applications.

As previously mentioned, only two tree characteristics (for a given species) are important to the DFTM Outbreak Model: the percentage new foliage and foliage biomass of the midcrown sample branch. Recall that these two foliage attributes are assigned to each tree using the procedures described with the BIOMASS keyword. The compression routine is simply a procedure for deciding which trees are most alike with respect to their foliage complements.

Two keywords control this compression: NUMCLASS and WEIGHT. The relative importance of the two foliage characteristics is determined by WEIGHT. And the NUMCLASS keyword determines the number of tree classes (Field 1 or 2, depending on the species) to be created, using the following procedure:

1. The mean and standard deviation for each foliage characteristic are calculated. Each tree's foliage characteristics are then "standardized" by subtracting the mean and dividing by the standard deviation of the appropriate foliage characteristic.

2. A new attribute is then created for each tree; call this attribute A. This attribute is the weighted sum of the standardized foliage characteristics; the weights used to multiply each standardized foliage characteristic in this sum are specified on the WEIGHT keyword card. Attribute A is then sorted into descending order, and used by the following two compression algorithms to assign trees to tree classes:

3. The first compression algorithm finds the largest gaps (or differences or distances) between adjacent sorted A values. These gaps become the boundaries for compression. All trees between two adjacent gaps are classified or grouped into the same tree class. This algorithm is intended to find those trees (or groups of trees) that have foliage characteristics that are very unusual, and should therefore not be combined with other trees into the same tree class. Generally speaking, this first compression algorithm does a good job of finding

such unusual trees, but in the process creates a few tree classes that contain a large number of trees (which are relatively similar). Additional discussion of this algorithm is given by Monserud (1978a, p. 59–61; see rule 4B). The proportion of the total number of tree classes determined by this algorithm is specified by parameter 3 of the NUMCLASS keyword.

4. The remaining available tree classes are determined by the second compression algorithm, which works as follows: The tree class containing the largest number of tree records is split into two classes, so that each class contains half of the records in the original class. Again the tree class containing the largest number of tree records is found, and then split evenly into two classes. This algorithm is repeated until the number of tree classes specified on the NUMCLASS keyword is created. The second compression alogrithm is intended to insure that one tree class does not contain an excessively large number of tree records, even though the foliage characteristics of those trees are relatively similar.

NUMCLASS — Specifies the number of tree classes to be created for each host species (Fields 1 and 2), and the proportion of tree classes to be created by the first tree compression algorithm (Field 3). All trees in a given tree class will be represented by one midcrown sample branch in the DFTM Outbreak Model.

- Field 1: Number of Douglas-fir tree classes; default is 20.
- Field 2: Number of grand fir tree classes; default is 20. (Note: the sum of Fields 1 and 2 must not exceed 100)
- Field 3: Proportion of tree classes determined by the first tree class compression algorithm (see preceding discussion); default is 0.50.

WEIGHT — Specify the relative importance of the two foliage variables used by the algorithm for compressing the list of trees into the number of tree classes specified by the NUMCLASS keyword (see discussion preceding NUMCLASS keyword). The default values result in percentage new foliage and foliage biomass being equally important.

- Field 1: The weight given to percentage new foliage; the default value is 1.0.
- Field 2: The weight given to foliage biomass; the default value is 1.0.

REDIST — Specify the annual redistribution rate of insects between tree classes (see Colbert and Wong 1979, p. 54). In effect, the redistribution rate (Field 1) operates by reducing the variation between the number of insects per tree class (weighted by the number of trees per tree class). The default redistribution rate of 0.25 will reduce the between tree class variation in insects by 25 percent for each year of the outbreak. A rate of 0.0 results in no redistribution, and a rate of 1.0 results in completely uniform redistribution, with the same number of insects in each tree class after the first year of the outbreak.

- Field 1: The annual tussock moth redistribution rate; default is 0.25.

DFTM Control and Stand Management Options

The CHEMICAL, NPV2, and NPV3 keywords are available for simulating the effect of applying either a chemical control or a virus, at various occasions during the outbreak. If the user desires to simulate a control measure that is not in the available list, then the TMPARMS keyword can be used to alter the appropriate mortality rates or growth parameters in the DFTM Outbreak Model; in this case, Colbert and Wong (1979) must be consulted to calculate the appropriate parameter value. A SALVAGE option is also available.

CHEMICAL — Chemical control will be applied in the phase of the outbreak specified in Field 1 to the instar specified in Field 2, and with the efficacy specified in Field 3. Note that any number of CHEMICAL keywords can be used.

Field 1: Phase (year) of the outbreak when chemical control will be applied; default is 3.

Field 2: Instar that will be targeted for control; default is 4.

Field 3: Instar specific mortality rate resulting from the chemical control treatment; default is 0.95.

NPV2 — Nuclear polyhedrosis virus will be applied in Phase II.

NPV3 — Nuclear polyhedrosis virus will be applied in Phase III.

SALVAGE — At the end of a tussock moth outbreak, salvage all surviving host trees that have been defoliated more than the percentage tree defoliation specified in Field 1.

Field 1: The minimum percentage tree defoliation for trees that will be salvaged; default is 50.0.

TMPARMS — This keyword has been provided for experienced users who have need to change additional parameters in the DFTM Outbreak Model. The parameters in question are most of those which make up the "PARAMETER" file as described in appendix A of Colbert and Wong (1979). The DFTM submodel described here contains an internal storage area which acts as a surrogate to their PARAMETER file; the TMPARMS keyword can be used to replace any parameter in this storage area. Colbert and Wong (1979) have defined the PARAMETERS and illustrated how new values are calculated. They have also prepared a table (see appendix A of their paper) which refers to the variables by data-card number, represented by the letter *i*, and value-on-the-card number, represented by the letter *j*. These same values, *i* and *j*, are used to reference the parameter values to be redefined in the Combined Model. Note that the parameter value will be reset to its default value if additional stands are processed in the same run.

Field 1: The card or record number (*i*, as described by Colbert and Wong 1979, p. 41–46), which contains the parameter to be replaced in the DFTM submodel storage area. The value of *i* must equal an integer from 2 to 12 or 19 to 25.

Field 2: The *j*th value on the *i*th card which corresponds to the parameter to be replaced in the DFTM submodel storage area. The value of *j* must equal an integer from 1 to 6.

Field 3: The value which is to replace the parameter corresponding to the *j*th value on the *i*th card in the parameter file. An error will occur if this or either of the preceding two fields are left blank.

To illustrate the use of the TMPARMS keyword, table 1 lists the parameter values for TMPARMS keywords that will mimic the two virus control keywords defined previously. When a virus control keyword (NPV2 or NPV3) is used, the instar-specific daily disease mortality rates listed by Colbert and Wong (1979, p. 42–43) are replaced by the mortality rates found in Field 3 in table 1.

Table 1.—Parameter values on the **TMPARMS** keyword(s) that will mimic the virus control keywords; note that four **TMPARMS** keywords are needed to mimic each of the virus control keywords

Keyword to be mimicked	Parameters of the TMPARMS keyword Field 1	Field 2	Field 3
NPV2	3	3	0.036
	3	4	.039
	3	5	.042
	3	6	.072
NPV3	4	3	.036
	4	4	.039
	4	5	.042
	4	6	.072

Example 5.

You would like to rerun the simulation in example 3, but with the following additions: simulate a chemical control with 90 percent efficacy applied in Phase III of the outbreak to the second instar, and salvage all trees that were defoliated more than 75 percent:

```
DFTM
MANSCHED    1.
RANLARVA    1.     9.     4.
RANLARVA    2.    12.     4.
BIOMASS     1.
CHEMICAL    3.     2.     0.90
SALVAGE    75.
END
```

INFORMATION PRODUCED

The Combined Model displays a variety of output tables which summarize the operation of the DFTM Outbreak Model during the course of the simulation. The DFTM Options and Input Table summarizes and describes the keywords that are in effect during the simulation. The DFTM Outbreak Summary Table lists the information germane to the scheduling and timing of outbreaks. The DFTM Defoliation Statistics Table—which is produced for each outbreak—displays the effect of tussock moth defoliation on each tree class.

These tussock moth outputs supplement the normal output tables produced by the Stand Prognosis Model (see Stage 1973, and Wykoff et al. 1982 for examples). An example of each type of output will be provided in the following discussion. A listing of the runstream that produced the simulation output illustrated in this section can be found in appendix A.

DFTM Options and Input Table

A brief summary of the important tussock moth keywords and parameter values used in a given stand projection is contained in the DFTM Options and Input Table (fig. 3). The keywords are listed in the left-hand column. A short description of the keyword and the numeric parameter values used in the simulation then follow to the right, com-

```
DOUGLAS-FIR TUSSOCK MOTH IN DOUGLAS-FIR AND GRAND FIR:  DFTM VERSION 3.1;  PROGNOSIS (INLAND EMPIRE) 4.0

                                   STAND ID= YRID-123; MANAGEMENT ID= F3T7

------------------------------------------ DFTM OPTIONS AND INPUT TABLE ----------------------------------------------

KEYWORD   KEYWORD DISCRIPTION AND PARAMETER VALUES USED
--------  ------------------------------------------------------------------------------------------------------------

RANSCHED  REGIONAL OUTBREAKS AUTOMATICALLY SCHEDULED.
          MINIMUM WAITING PERIOD IS   30 YEARS; EVENT PROBABILITY IS  0.100
          LAST RECORDED TUSSOCK MOTH OUTBREAK WAS IN YEAR:  1492

RANSTART  STAND INCLUSION IN REGIONAL OUTBREAKS IS STOCHASTICALLY DETERMINED (SEE PROBMETH).

PROBMETH  CONDITIONAL PROBABILITY OF STAND BEING INCLUDED IN A REGIONAL OUBREAK IS A FUNCTION OF:
          ELEV, SLOPE, ASPECT, TOPO, CROWN CLOSURE, CROWN WIDTH, AND %HOST (METHOD 1)
          PROBABILITY SCALING FACTOR = 1.000

TOPO      TOPOGRAPHIC POSITION CODE =   1.00;  1=RIDGETOP,2=SIDEHILL,3=BOTTOM.

ASHDEPTH  SOIL ASH DEPTH IN INCHES =    15.930

RANLARVA  RANDOM FIRST INSTAR LARVAE ASSIGNMENT FOR SPECIES  1 (DF)
          AVERAGE =  14.00; WITHIN-OUTBREAK STANDARD DEVIATION =  2.00; BETWEEN-OUTBREAK STANDARD DEVIATION =  0.0

RANLARVA  RANDOM FIRST INSTAR LARVAE ASSIGNMENT FOR SPECIES  2 (GF)
          AVERAGE -  14.00; WITHIN-OUTBREAK STANDARD DEVIATION =  2.00; BETWEEN-OUTBREAK STANDARD DEVIATION =  0.0

BIOMASS   ASSIGNMENT USING BASAL AREA PERCENTILE AND SPECIES, WITH ADDITIVE RANDOM VARIATION (METHOD 4)

NUMCLASS  NUMBER OF REQUESTED CLASSES OF DOUGLAS-FIR=  20; GRAND FIR- 20
          PROPORTION OF CLASSES DEFINED BY FINDING DIFFERENCES BETWEEN TREES =  0.50
          THE REMAINING CLASSES ARE FOUND BY HALVING THE CLASSES WITH THE MOST TREE RECORDS.

WEIGHT    THE CLASSIFICATION WEIGHTING FACTORS ARE:   1.00 FOR % NEW FOLIAGE, AND   1.00 FOR FOLIAGE BIOMASS.

REDIST    ANNUAL TUSSOCK MOTH REDISTRIBUTION RATE =  0.25

SALVAGE   SALVAGE SURVIVORS AFTER EVERY OUTBREAK.  CRITICAL TREE DEFOLITION LEVEL =  90.0%

RANNSEED  DFTM RANDOM NUMBER GENERATOR WAS RESEEDED:          49          69          89

----------------------------------------------------------------------------------------------------------------------
```

Figure 3.—Sample output from the Combined Model: DFTM Options and Input Table.

prising the main body of the table. Note that the DFTM Options and Input Table is designed to display only the options in effect for the simulation; it does not include all of the available keywords. Also note that the DFTM keywords that are explicitly specified by the user are also listed (in the order specified) in the "Options Selected by Input" table in the Stand Prognosis Model (see Wykoff et al. 1982 for an example).

DFTM Outbreak Summary Table

The DFTM Outbreak Summary Table (fig. 4) displays the timing of tussock moth outbreaks in summary form. The Combined Model contains logic that controls the process of selecting which cycles (i.e., projection periods) will contain a tussock moth outbreak. As discussed earlier, there are two steps in this decision process. The first step schedules the timing of regional outbreaks and the second determines which of the regional outbreaks will include the subject stand.

DFTM OUTBREAK SUMMARY TABLE

CYCLE NUMBER	CYCLE YEARS	YEAR OF REGIONAL DFTM OUTBREAK	CONDITIONAL PROBABILITY OF STAND OUTBREAK	WAS THERE AN OUTBREAK IN STAND YRID-123?
1	1971 - 1976	1971	0.843	YES
2	1976 - 1981		0.496	NO
3	1981 - 1991		0.542	NO
4	1991 - 2001		0.664	NO
5	2001 - 2006		0.740	NO
6	2006 - 2011	2006	0.763	YES
7	2011 - 2021		0.418	NO

Figure 4.—Sample output from the Combined Model: DFTM Outbreak Summary Table.

The first three columns of the Tussock Moth Outbreak Summary Table (fig. 4) list the outcome of the first step of the outbreak scheduling logic. A list of the Prognosis Model cycles is contained in the first two columns. The third column contains a list of the regional outbreak years. When the RANSCHED option is used, as is the case in this example, a series of regional outbreak dates are stochastically generated. These outbreak dates are assigned to existing projection cycles if one can be found that starts within ± 2 years of the regional outbreak; otherwise a 5-year cycle is inserted.

The remainder of the table summarizes the second step of the outbreak decision logic. The fourth column contains a list of conditional probabilities that the subject stand will be included in the regional outbreak. Note that a conditional probability is printed for every cycle, even though there may be no regional outbreak scheduled in that cycle. In addition, note that these conditional probabilities are used only when the RANSTART option is specified (as it was in the example presented here). The last column indicates whether or not the subject stand was included in the regional outbreak; only then is the DFTM Outbreak Model called.

The user should be aware that the sampling basis of the DFTM damage model is approximately 5 years (Wickman 1978a). When the user specifies that cycle lengths other than 5 years are to be used, the Combined Stand Prognosis/DFTM Outbreak Model automatically inserts and/or deletes cycles such that each cycle which contains a tussock moth outbreak is 5 years long.[4] In the example simulation summarized in figure 4, 5-year tussock moth cycles were inserted in the first and next-to-last projection cycles; both cycles would have been 10 years long (1971-1981 and 2001-2011) in the absence of regional tussock moth outbreaks.

The insertion and/or deletion of cycles is done only when necessary. The timing of the Prognosis Model management options, such as thinning, will remain intact regardless of the number of cycles inserted. Occasionally the deletion of a cycle will force a management option to be rescheduled to the next available cycle. Warning messages are printed to inform the user of the action taken by the combined model.

[4]There is one exception to this rule. When MANSCHED scheduling is used in conjunction with the MANSTART option, it is possible to force the Combined Model to simulate a 4- or 6-year long tussock moth outbreak. When either of these cases arises, a warning message will be printed.

DFTM Defoliation Statistics Table

Figure 5 illustrates the output summarizing each tussock moth outbreak. The first several lines contain a message indicating which years of the subject stand's development include the outbreak that is detailed in the rest of the table. A message is also printed indicating when a salvage is scheduled.

The main body of figure 5 consists of the "Summary of Tree Class Characteristics." A row of summary statistics is printed for each tree class, which is a collection of trees with similar foliage attributes—the only tree characteristics important to the DFTM Outbreak Model. These statistics are divided into two groups: "Before Outbreak" (columns 1-10) and "After Outbreak" (columns 11-19). The last three rows contain weighted averages of the same characteristics for each host species (Douglas-fir and grand fir) and for all host species combined. Except for the columns labeled "Records per tree class" and "Trees per acre" (columns 3 and 4), all summary statistics printed in this figure are averages weighted by the number of trees per acre (column 4) represented by each tree in a given tree class.

Percentage branch defoliation (column 11) is the only variable in figure 5 directly predicted by the DFTM Outbreak Model. Percentage branch defoliation is converted to percentage tree defoliation (column 12) using the function illustrated in figure 2. The insensitivity of percentage tree defoliation to any amount of branch defoliation below 55 percent can be seen from examining columns 11 and 12 in the "Summary of Tree Class Characteristics" table illustrated in figure 5; the extreme sensitivity of the relationship graphed in figure 2 is also apparent for values of branch defoliation between 60 and 90 percent. The predictions of mortality, top-kill, and diameter and height growth loss are all functions of percentage tree defoliation.

Recall that tree mortality (or survival) is modeled as a continuous rather than a discrete event in the Stand Prognosis Model (Stage 1973; Monserud 1978a). Mortality operates by reducing the number of trees per acre represented by a given tree record. Thus the number of trees per acre in a given tree class after the outbreak equals the product of the trees per acre before the outbreak (column 4) and 1.0 minus the 5-year mortality rate (column 13). Of course it would not be correct to attribute the reduction in trees per acre solely to the tussock moth, for the normal mortality rate in the absence of a tussock moth outbreak is certainly greater than zero.

Top-kill is not modeled in the same manner as mortality however, for top-kill is treated as a discrete event in the combined model. Monserud (1978a, p. 67–68) detailed the procedure for stochastically determining whether or not a given tree will have top-kill, and how much. The average amount of top-kill for each tree class is summarized in columns 18 and 19 of figure 5. As a result of top-kill, the total height, live crown ratio, and volume of a tree are reduced accordingly; the procedure for calculating the volume of a top-killed tree is discussed by Monserud (1980, 1981).

The effect of tussock moth defoliation on diameter and height growth can be seen in columns 14–17 of figure 5; the sum of net growth and growth loss equals the growth in the absence of tussock moth defoliation. Note that the change in height columns (16 and 17) include top-kill losses. Because top-kill losses can potentially exceed height growth, net change in height can be negative (see column 16 in figure 5 for tree classes 9 and 22). The average amount of top-kill as a percentage of live crown length is displayed in column 19 of figure 5.

DFTM DEFOLIATION STATISTICS FOR STAND YRID-123; MANAGEMENT ID- F3T7

THE FIRST YEAR OF THIS SIMULATED TUSSOCK MOTH OUTBREAK IS YEAR 1971. IT IS BEING SIMULATED
AS PART OF CYCLE 1 WHICH REPRESENTS YEARS 1971 TO 1976 IN THIS STANDS DEVELOPMENT.

SUMMARY OF TREE CLASS CHARACTERISTICS

BEFORE OUTBREAK

TREE CLASS NO.	HOST SPP.	RECORDS PER TREE CLASS	TREES PER ACRE	DBH (IN)	HEIGHT (FT)	LIVE CROWN RATIO	MIDCROWN SAMPLE BRANCH: PERCENT NEW FOLIAGE	MIDCROWN SAMPLE BRANCH: FOLIAGE BIOMASS (GRAMS)	MIDCROWN SAMPLE BRANCH: FIRST INSTAR LARVAE
1	DF	1	0.4	24.9	85.1	0.48	37.4	400.0	14.2
2	DF	2	1.9	12.9	68.1	0.36	42.0	301.7	19.2
3	DF	5	5.8	18.7	88.6	0.48	41.7	263.3	14.5
4	DF	4	4.0	18.3	74.5	0.31	39.3	254.3	17.0
5	DF	2	3.0	9.4	52.3	0.47	25.5	317.1	14.8
6	DF	11	9.6	7.7	45.4	0.35	35.6	228.6	16.1
7	DF	6	4.4	10.6	63.1	0.34	31.1	241.3	14.7
8	DF	6	3.9	9.3	50.1	0.42	37.2	192.2	14.5
9	DF	7	4.7	9.0	51.1	0.41	28.8	224.4	14.5
10	DF	7	5.6	6.5	41.9	0.40	26.5	225.1	12.1
11	DF	9	6.6	3.8	29.5	0.33	27.3	196.4	10.4
12	DF	11	8.5	7.4	43.2	0.37	20.0	213.8	12.9
13	DF	12	12.0	4.0	28.4	0.32	18.0	210.2	12.0
14	DF	11	9.4	3.1	22.7	0.21	24.9	155.0	16.2
15	DF	12	9.7	3.4	24.9	0.23	19.0	175.5	15.6
16	DF	11	6.2	3.4	25.2	0.30	19.5	156.4	12.2
17	DF	12	10.9	3.1	21.8	0.32	15.2	166.9	14.7
18	DF	11	8.5	3.0	22.6	0.29	14.8	142.4	12.9
19	DF	12	9.7	4.1	29.7	0.27	13.4	126.1	17.1
20	DF	7	7.6	1.7	12.4	0.21	11.2	93.3	12.7
21	GF	1	0.4	12.9	63.2	0.47	47.0	351.8	15.2
22	GF	2	2.1	11.8	59.2	0.46	39.5	374.1	14.5
23	GF	2	1.0	15.4	64.8	0.58	47.0	303.6	11.5
24	GF	4	3.7	6.5	38.7	0.35	45.5	299.3	12.7
25	GF	3	3.6	7.2	34.2	0.29	43.5	304.2	9.2
26	GF	32	27.7	8.9	45.6	0.41	40.3	279.1	9.5
27	GF	32	27.0	8.4	47.4	0.38	39.5	254.7	13.2
28	GF	64	55.6	5.1	29.7	0.37	38.1	237.5	15.2
29	GF	32	29.1	4.9	29.0	0.34	37.7	213.1	16.1
30	GF	32	25.7	4.8	28.8	0.40	37.2	203.0	15.5
31	GF	64	49.9	5.2	30.3	0.34	33.9	206.6	16.4
32	GF	32	29.7	4.4	27.7	0.35	35.1	178.3	15.3
33	GF	32	23.1	5.1	28.6	0.31	33.1	181.2	10.8
34	GF	64	49.1	4.8	28.7	0.36	31.2	175.9	10.4
35	GF	64	57.4	3.6	22.0	0.32	29.6	154.5	14.4
36	GF	64	52.6	4.0	25.0	0.33	24.0	146.4	12.9
37	GF	1	0.4	1.8	10.2	0.28	21.3	125.0	14.5
38	GF	4	2.9	4.8	30.2	0.32	16.4	149.0	16.7
39	GF	1	0.6	1.8	10.2	0.32	17.5	125.0	14.9
40	GF	1	0.6	7.9	46.7	0.17	16.7	125.0	17.2
AVERAGE	DF	7.9	6.6	6.1	36.5	0.32	23.3	190.8	14.2
AVERAGE	GF	26.5	22.1	5.2	30.2	0.35	33.7	199.7	13.7
AVERAGE	HOST	17.3	14.4	5.4	31.7	0.35	31.3	197.6	13.9

AFTER OUTBREAK

TREE CLASS NO.	HOST SPP.	PRECENTAGE DEFOLIATION: BRANCH (%)	PRECENTAGE DEFOLIATION: TREE (%)	FIVE YEAR MORT RATE	5 YEAR CHANGE IN: DIAMETER NET (IN)	5 YEAR CHANGE IN: DIAMETER LOSS (IN)	5 YEAR CHANGE IN: HEIGHT NET (FT)	5 YEAR CHANGE IN: HEIGHT LOSS (FT)	AMOUNT OF TOP-KILL (FT)	AMOUNT OF TOP-KILL (%)
1	DF	91.25	95.39	0.591	0.05	0.07	1.13	0.25	0.0	0.0
2	DF	100.00	100.00	0.940	0.09	0.14	2.01	0.50	0.0	0.0
3	DF	100.00	100.00	0.940	0.14	0.23	1.89	0.47	0.0	0.0
4	DF	100.00	100.00	0.940	0.10	0.16	1.74	0.43	0.0	0.0
5	DF	100.00	100.00	0.940	0.11	0.18	2.68	0.67	0.0	0.0
6	DF	100.00	100.00	0.940	0.11	0.17	2.76	0.69	0.0	0.0
7	DF	92.75	96.18	0.591	0.15	0.24	2.76	0.73	0.2	1.3
8	DF	98.37	97.62	0.591	0.13	0.20	2.31	0.57	0.0	0.0
9	DF	84.34	86.16	0.373	0.23	0.17	-0.32	4.00	3.5	11.1
10	DF	88.45	93.06	0.373	0.18	0.14	0.97	2.50	2.1	11.2
11	DF	74.91	45.16	0.085	0.19	0.10	3.09	0.59	0.0	0.0
12	DF	69.42	19.45	0.076	0.23	0.09	2.70	0.67	0.4	2.0
13	DF	67.21	12.80	0.076	0.21	0.04	2.98	0.49	0.0	0.0
14	DF	95.66	97.14	0.591	0.08	0.13	2.58	0.53	0.0	0.5
15	DF	78.37	63.87	0.085	0.13	0.07	2.74	0.63	0.3	3.6
16	DF	77.75	60.70	0.085	0.17	0.09	2.76	0.51	0.2	2.8
17	DF	71.03	25.74	0.076	0.17	0.07	2.89	0.45	0.0	0.6
18	DF	70.60	23.91	0.076	0.18	0.07	2.89	0.51	0.0	0.3
19	DF	48.35	0.21	0.073	0.19	0.03	3.06	0.33	0.0	0.0
20	DF	28.36	0.00	0.070	0.17	0.03	2.45	0.15	0.0	0.0
21	GF	100.00	99.56	0.934	0.13	0.15	2.46	0.62	0.0	0.0
22	GF	86.82	90.94	0.266	0.43	0.34	-9.22	13.92	13.6	54.1
23	GF	99.29	97.72	0.555	0.48	0.58	3.93	0.97	0.0	0.0
24	GF	100.00	98.67	0.555	0.19	0.22	2.79	0.70	0.0	0.0
25	GF	92.16	95.90	0.555	0.23	0.28	2.51	1.32	0.8	32.0
26	GF	90.68	95.02	0.555	0.26	0.32	2.27	1.62	1.0	5.8
27	GF	100.00	100.00	0.934	0.23	0.28	3.07	0.77	0.0	0.0
28	GF	100.00	100.00	0.934	0.24	0.28	2.61	0.69	0.0	0.1
29	GF	97.05	97.42	0.555	0.21	0.26	2.33	0.82	0.3	3.1
30	GF	86.62	90.64	0.266	0.29	0.23	1.12	2.03	1.6	12.5
31	GF	87.96	92.50	0.266	0.30	0.24	2.48	0.89	0.4	4.6
32	GF	92.37	96.00	0.555	0.21	0.26	1.93	1.30	0.7	2.8
33	GF	86.83	90.96	0.266	0.28	0.22	2.65	0.50	0.0	1.0
34	GF	85.80	89.24	0.266	0.29	0.23	1.94	1.26	0.8	5.9
35	GF	89.70	94.27	0.266	0.26	0.20	2.18	0.70	0.3	4.1
36	GF	77.55	59.65	0.065	0.28	0.17	2.37	0.62	0.2	1.8
37	GF	74.26	41.63	0.066	0.10	0.06	1.67	0.42	0.0	0.0
38	GF	61.58	3.96	0.065	0.35	0.10	2.85	0.40	0.0	0.0
39	GF	65.01	8.21	0.066	0.54	0.15	1.81	0.27	0.0	0.0
40	GF	65.60	9.26	0.063	0.58	0.16	3.98	0.60	0.0	0.0
AVERAGE	DF	77.32	54.40	0.328	0.16	0.11	2.52	0.72	0.3	1.6
AVERAGE	GF	89.81	89.63	0.427	0.26	0.24	2.24	1.02	0.5	4.0
AVERAGE	HOST	86.93	81.51	0.404	0.24	0.21	2.31	0.95	0.4	3.4

Figure 5.—Sample output from the Combined Model: DFTM Defoliation Statistics Table.

Other Output

As discussed earlier, the defoliation estimates made by the DFTM submodel are automatically transmitted to the Prognosis Model and translated into tree damage. Thus, any tree mortality, growth reductions, and volume losses attributable to tussock moth are reflected in the normal output produced by the Stand Prognosis Model.

Figures 6 and 7 are examples of the two major displays produced by the Prognosis Model; these output tables are discussed by Stage (1973, p. 3-5) and Wykoff et al. (1982). An examination of figure 6 reveals that mortality losses were estimated to be 400 ft^3/acre/yr during the simulated outbreak that began in 1971. During this outbreak, 52 percent of the volume lost was grand fir and 45 percent was Douglas-fir (see the species composition summary on the right half of figure 6). The outbreak was followed by a salvage that removed 989 ft^3/acre in the year 1976 (all trees with tree defoliation exceeding 90 percent were salvaged). In figure 7 it can be seen that stand basal area was reduced from 173 ft^2/acre before the 1971 outbreak to 99 ft^2/acre after the outbreak; the salvage cut reduced it further to 57 ft^2/acre. It is evident from both figures 6 and 7 that the combined model predicted that the stand contained 618 trees per acre before the 1971 outbreak, 382 trees per acre after the outbreak, and 210 trees per acre after the salvage at the end of the 1971 outbreak.

Finally, optional tussock moth output is printed if the user specifies the proper keyword(s); see the descriptions of the DEBUG, DEBUTREE, and PUNCH keywords for details.

STAND GROWTH PROGNOSIS SYSTEM   VERSION 4.0 -- INLAND EMPIRE

STAND ID: YRID-123   MANAGEMENT CODE: F317   BAMAX 220 -- RUN WICKMANS Y-RIDGE PLOTS WITH VERSION 4.0

STAND COMPOSITION

YEAR	STAND ATTRIBUTES	PERCENTILE POINTS IN THE DISTRIBUTION OF STAND ATTRIBUTES BY DBH (DBH IN INCHES) 10	30	50	70	90	100	TOTAL/ACRE OF STAND ATTRIBUTES	DISTRIBUTION OF STAND ATTRIBUTES BY SPECIES AND 3 USER-DEFINED SUBCLASSES
1971	TREES	1.8	3.0	4.5	6.8	10.8	27.1	618. TREES	72.% GF1, 21.% DF1, 4.% L1, 2.% PP1
	VOLUME:								
	TOTAL	6.7	9.9	13.7	19.5	27.1	27.1	4345. CUFT	46.% GF1, 29.% DF1, 12.% PP1, 10.% L1
	MERCH	8.6	11.1	17.2	19.8	27.1	27.1	3596. CUFT	42.% GF1, 30.% DF1, 13.% PP1, 10.% L1
	MERCH	10.8	15.1	19.5	20.8	27.1	27.1	14499. BDFT	33.% DF1, 33.% GF1, 16.% PP1, 11.% L1
	ACCRETION	4.8	7.4	9.8	14.2	27.1	27.1	53. CUFT/YR	54.% GF1, 16.% PP1, 14.% L1, 11.% DF1
	MORTALITY	7.1	10.5	13.7	19.5	24.9	27.1	400. CUFT/YR	52.% GF1, 45.% DF1, 2.% PP1, 1.% L1
1976	TREES	1.9	3.1	4.3	6.6	10.2	28.2	382. TREES	66.% GF1, 23.% DF1, 7.% L1, 2.% PP1
	VOLUME:								
	TOTAL	6.4	9.4	13.7	20.2	27.6	28.2	2612. CUFT	42.% GF1, 20.% PP1, 16.% L1, 14.% DF1
	MERCH	8.6	11.1	16.4	20.7	27.6	28.2	2136. CUFT	39.% GF1, 23.% PP1, 18.% L1, 13.% DF1
	MERCH	11.0	14.5	20.0	21.5	27.6	28.2	8647. BDFT	30.% GF1, 27.% PP1, 19.% L1, 13.% S1
	REMOVAL	1.9	3.1	4.3	7.0	10.2	25.2	173. TREES	92.% GF1, 7.% DF1, 1.% GF3, 0.% ---
	VOLUME:								
	TOTAL	6.4	9.0	11.1	16.4	21.1	25.2	989. CUFT	84.% GF1, 16.% DF1, 0.% GF3, 0.% ---
	MERCH	8.3	9.9	11.8	17.5	21.1	25.2	801. CUFT	82.% GF1, 18.% DF1, 0.% ---, 0.% ---
	MERCH	10.1	11.8	16.4	20.4	21.1	25.2	2837. BDFT	79.% GF1, 21.% DF1, 0.% ---, 0.% ---
	RESIDUAL	2.0	3.1	4.3	6.4	10.2	28.2	210. TREES	44.% GF1, 37.% DF1, 12.% L1, 4.% PP1
	ACCRETION	3.9	6.5	8.2	13.5	27.6	28.2	67. CUFT/YR	35.% GF1, 22.% PP1, 20.% DF1, 17.% L1
	MORTALITY	5.9	9.2	14.0	20.2	27.6	28.2	9. CUFT/YR	30.% L1, 29.% PP1, 21.% GF1, 14.% DF1
1981	TREES	2.5	3.8	4.9	7.3	10.9	28.8	202. TREES	44.% GF1, 37.% DF1, 12.% L1, 5.% PP1
	VOLUME:								
	TOTAL	6.7	9.9	14.9	21.1	28.8	28.8	1912. CUFT	30.% PP1, 25.% L1, 20.% GF1, 14.% DF1
	MERCH	8.6	12.5	17.9	28.1	28.8	28.8	1604. CUFT	35.% PP1, 27.% L1, 16.% GF1, 12.% S1
	MERCH	11.1	14.9	21.1	28.6	28.8	28.8	6808. BDFT	39.% PP1, 25.% L1, 18.% S1, 10.% GF1
	ACCRETION	4.0	6.4	8.3	10.9	28.1	28.8	91. CUFT/YR	42.% GF1, 24.% DF1, 17.% PP1, 14.% L1
	MORTALITY	6.0	9.1	14.1	20.6	28.8	28.8	12. CUFT/YR	27.% PP1, 27.% L1, 24.% GF1, 15.% DF1
1991	TREES	4.3	5.4	7.3	9.4	13.3	31.0	186. TREES	44.% GF1, 37.% DF1, 12.% L1, 5.% PP1
	VOLUME:								
	TOTAL	7.5	10.1	14.2	18.6	31.0	31.0	2694. CUFT	27.% GF1, 26.% PP1, 21.% L1, 18.% DF1
	MERCH	9.0	11.1	15.8	22.0	31.0	31.0	2329. CUFT	29.% PP1, 26.% GF1, 22.% L1, 13.% DF1
	MERCH	10.4	14.3	18.5	29.0	31.0	31.0	10030. BDFT	33.% PP1, 23.% L1, 20.% GF1, 14.% S1
	ACCRETION	5.3	7.9	9.8	11.9	18.6	31.0	104. CUFT/YR	46.% GF1, 25.% DF1, 13.% L1, 11.% PP1
	MORTALITY	6.7	9.9	13.6	18.5	31.0	31.0	19. CUFT/YR	30.% GF1, 24.% PP1, 22.% L1, 18.% DF1

2001	TREES	5.7	7.2	9.0	11.1	15.0	32.2	171	TREES	44.% GF1,	37.% DF1,	12.% L1,	5.% PP1
	VOLUME:												
	TOTAL	8.1	11.3	14.0	18.5	32.2	32.2	3544.	CUFT	33.% GF1,	22.% PP1,	20.% DF1,	19.% L1
	MERCH	9.5	11.8	14.7	19.3	32.2	32.2	3181.	CUFT	33.% GF1,	23.% PP1,	19.% L1,	16.% DF1
	MERCH	10.8	13.5	17.2	24.3	32.2	32.2	13915.	BDFT	29.% GF1,	27.% PP1,	21.% L1,	12.% DF1
	ACCRETION	7.0	9.7	11.6	14.0	19.3	32.2	110.	CUFT/YR	52.% GF1,	23.% DF1,	12.% PP1,	10.% L1
	MORTALITY	8.0	11.2	14.0	17.4	31.2	32.2	27.	CUFT/YR	35.% GF1,	20.% PP1,	19.% DF1,	19.% L1
2006	TREES	6.0	7.6	9.6	11.8	15.9	32.8	164.	TREES	44.% GF1,	37.% DF1,	12.% L1,	5.% PP1
	VOLUME:												
	TOTAL	8.7	11.7	14.8	18.2	31.9	32.8	3962.	CUFT	35.% GF1,	20.% PP1,	20.% DF1,	17.% L1
	MERCH	9.5	12.3	15.3	18.6	32.8	32.8	3612.	CUFT	36.% GF1,	22.% PP1,	18.% L1,	17.% DF1
	MERCH	10.7	13.8	17.0	24.4	32.8	32.8	16175.	BDFT	33.% GF1,	25.% PP1,	19.% L1,	13.% DF1
	ACCRETION	7.2	10.5	13.0	17.0	31.9	32.8	57.	CUFT/YR	30.% GF1,	23.% PP1,	22.% L1,	18.% DF1
	MORTALITY	9.1	11.5	13.9	15.9	18.2	32.8	239.	CUFT/YR	60.% GF1,	33.% DF1,	3.% PP1,	2.% L1
2011	TREES	6.2	7.5	9.5	11.6	16.9	33.4	109.	TREES	37.% DF1,	34.% GF1,	18.% L1,	7.% PP1
	VOLUME:												
	TOTAL	8.7	12.2	15.7	20.9	33.4	33.4	3050.	CUFT	27.% PP1,	24.% GF1,	24.% L1,	15.% DF1
	MERCH	9.5	12.8	16.7	25.0	33.4	33.4	2802.	CUFT	29.% PP1,	25.% L1,	25.% GF1,	11.% DF1
	MERCH	11.5	14.2	18.6	25.3	33.4	33.4	12981.	BDFT	33.% PP1,	25.% L1,	22.% GF1,	13.% S1
	REMOVAL	6.4	9.0	10.7	12.4	16.5	32.7	29.	TREES	75.% GF1,	24.% DF1,	2.% GF3,	0.% ---
	VOLUME:												
	TOTAL	9.2	11.3	13.9	16.5	18.6	32.7	647.	CUFT	80.% GF1,	19.% DF1,	1.% GF3,	0.% ---
	MERCH	9.5	11.9	14.3	16.5	18.6	32.7	599.	CUFT	81.% GF1,	18.% DF1,	1.% GF3,	0.% ---
	MERCH	10.8	12.8	15.2	16.7	18.8	32.7	2582.	BDFT	83.% GF1,	16.% DF1,	1.% GF3,	0.% ---
	RESIDUAL	6.1	7.3	9.0	11.5	17.6	33.4	80.	TREES	42.% DF1,	25.% L1,	19.% GF1,	9.% PP1
	ACCRETION	6.8	9.3	11.6	13.8	25.4	33.4	62.	CUFT/YR	27.% DF1,	24.% PP1,	23.% GF1,	21.% L1
	MORTALITY	8.3	12.3	17.4	25.0	33.4	33.4	12.	CUFT/YR	36.% L1,	32.% PP1,	13.% DF1,	12.% GF1
2021	TREES	7.0	8.4	10.4	13.0	18.5	34.7	76.	TREES	43.% DF1,	24.% L1,	19.% GF1,	9.% PP1
	VOLUME:												
	TOTAL	8.8	13.2	17.0	26.0	34.7	34.7	2907.	CUFT	33.% PP1,	28.% L1,	17.% DF1,	12.% GF1
	MERCH	9.6	13.6	18.1	26.0	34.7	34.7	2743.	CUFT	34.% PP1,	28.% L1,	15.% DF1,	12.% GF1
	MERCH	12.4	15.3	20.4	26.8	34.7	34.7	12857.	BDFT	38.% PP1,	29.% L1,	14.% S1,	11.% GF1

Figure 6.—Sample Stand Prognosis output from the Combined Model: Stand Table.

STAND GROWTH PROGNOSIS SYSTEM   VERSION 4.0 -- INLAND EMPIRE

STAND ID; YRID-123   MANAGEMENT CODE: F317   BAMAX = 220 -- RUN WICKMANS Y-RIDGE PLOTS WITH VERSION 4.0

	ATTRIBUTES OF SELECTED SAMPLE TREES								ADDITIONAL STAND ATTRIBUTES					
YEAR	INITIAL TREES/A %TILE	SPECIES	DBH (INCHES)	HEIGHT (FEET)	LIVE CROWN RATIO	PAST DBH GROWTH (INCHES)	BASAL AREA %TILE	TREES PER ACRE	STAND AGE	QUADRATIC MEAN DBH (INCHES)	TREES PER ACRE	BASAL AREA (SQFT/A)	HEIGHT OF DOMINANTS (FEET)	CROWN COMP FACTOR
1971						(10 YRS)								
	10	GF1	1.80	10.17	32	0.0	0.3	2.50						
	30	GF1	3.00	18.15	19	0.0	2.7	2.50						
	50	GF1	4.50	28.36	17	0.0	8.0	2.50						
	70	GF1	6.80	41.53	35	0.90	20.8	2.50						
	90	DF1	10.80	62.69	60	0.0	49.9	2.50						
	100	PP1	27.10	103.67	29	0.0	100.0	2.50	50	7.2	618.	173.	90.2	214.8
1976						(5 YRS)								
	10	GF1	2.01	11.90	32	0.19	0.5	1.84						
	30	GF1	3.15	20.28	23	0.14	3.4	1.11						
	50	GF1	4.69	30.94	22	0.17	10.7	1.84						
	70	GF1	7.07	44.63	40	0.25	24.8	1.84						
	90	DF1	11.10	65.55	63	0.26	56.3	2.31						
	100	PP1	27.62	106.14	34	0.46	97.4	2.35	55	6.9	382.	99.	94.0	122.8
									RESIDUAL:	7.1	210.	57.	103.4	63.0
1981						(5 YRS)								
	10	GF1	2.63	15.89	32	0.56	0.7	1.76						
	30	GF1	3.44	24.84	24	0.27	2.8	0.02						
	50	GF1	5.78	36.53	25	0.99	12.9	0.04						
	70	GF1	8.07	50.41	43	0.91	30.4	0.04						
	90	DF1	12.46	70.97	66	1.18	55.2	2.25						
	100	PP1	28.85	109.58	37	1.09	100.0	2.29	60	7.7	202.	65.	106.0	71.9
1991						(10 YRS)								
	10	GF1	4.95	24.41	38	2.13	3.4	1.59						
	30	GF1	5.21	34.53	26	1.62	4.9	0.02						
	50	GF1	7.58	47.11	26	1.65	17.6	0.03						
	70	GF1	9.78	61.12	43	1.56	36.5	0.03						
	90	DF1	15.06	81.09	67	2.25	66.7	2.12						
	100	PP1	31.01	115.82	37	1.92	100.0	2.16	70	9.3	186.	88.	104.8	97.3

2001						(10 YRS)								
	10	GF1	6.52	33.17	39	1.44	5.7	1.45						
	30	GF1	8.47	45.51	31	2.98	17.2	0.02						
	50	GF1	9.39	57.66	27	1.65	22.5	0.03						
	70	GF1	11.66	71.58	44	1.72	43.0	0.03						
	90	DF1	17.04	88.99	67	1.71	72.5	1.97						
	100	PP1	32.22	120.29	37	1.08	100.0	2.02						
									80	10.8	171.	109.	105.1	116.8
2006						(5 YRS)								
	10	GF1	7.46	38.13	39	0.85	8.3	1.39						
	30	GF1	9.18	50.26	30	0.65	17.7	0.02						
	50	GF1	9.75	61.25	26	0.33	21.7	0.03						
	70	GF1	12.44	76.08	43	0.72	43.8	0.03						
	90	DF1	18.18	92.75	67	0.99	78.8	1.90						
	100	PP1	32.80	122.34	36	0.51	100.0	1.94						
									85	11.5	164.	118.	107.4	123.5
2011						(5 YRS)								
	10	GF1	7.75	41.86	42	0.27	10.6	0.62						
	30	GF1	9.82	54.88	33	0.59	21.1	0.02						
	50	GF1	10.38	65.29	28	0.58	23.4	0.02						
	70	GF1	12.82	79.70	46	0.35	44.3	0.00						
	90	DF1	18.61	95.57	68	0.37	70.8	0.78						
	100	PP1	33.42	124.40	38	0.55	100.0	1.87						
									90	11.8	109.	83.	114.2	81.7
									RESIDUAL:	11.9	80.	62.	118.4	56.4
2021						(10 YRS)								
	10	GF1	9.10	51.91	42	1.24	13.9	0.01						
	30	GF1	11.33	64.56	33	1.39	25.7	0.01						
	50	GF1	11.19	72.38	28	0.74	22.8	0.02						
	70	GF1	13.96	87.30	46	1.04	43.3	0.00						
	90	DF1	19.84	100.99	68	1.07	67.2	0.01						
	100	PP1	34.71	128.46	38	1.15	100.0	1.78						
									100	13.1	76.	71.	122.4	64.0

Figure 7.—Sample Stand Prognosis output from the Combined Model: Sample Tree Summary Table.

BEHAVIOR OF THE COMBINED MODEL

The purpose of this section is to illustrate the behavior of the Combined Model when the major input options are varied. This section does not purport to be a sensitivity analysis, however. In all figures in this section, simulated stand volume development is plotted against time over the course of a 50- to 100-year projection, using the same stand. The sample stand simulated is B. E. Wickman's Y-Ridge plots 1, 2, and 3, as measured at the beginning of the 1971-74 Oregon Blue Mountains outbreak. This stand is two-storied with 70 percent of the trees less than 6.8 inches d.b.h. in 1971 (before the outbreak). The two host species for tussock moth comprise most of the stand: grand fir and Douglas-fir account for 72 and 21 percent of the trees per acre and 46 and 29 percent of the total volume in 1971, respectively.

The "no outbreak" curve will be the same on all figures, and indicates what the expected volume development over time would be for this stand if an outbreak had not occurred. Since the version of the Stand Prognosis Model used in this analysis did not include regeneration establishment, all simulation results reported here are based on projecting only trees and seedlings already established at the start of the outbreak. Thus, the simulations that produced heavy mortality or large salvage removals quite likely underestimate stand volume near the end of the 50-year projections.

Keep in mind that these examples are projections into the future, which obviously involves considerable uncertainty; our best guess should never be confused with certainty. Also keep in mind that this one sample stand (or any one stand) is unlikely to be typical of an area as large and diverse as the Blue Mountains of Oregon and Washington.

The reader should note that the figures to be presented in this section differ from and supersede the figures Monserud (1978b) presented with a preliminary description of the Combined Model. There are several reasons for the differences: (1) significant changes have been made to the Stand Prognosis Model since 1978, especially in the mortality model and to a lesser extent in the diameter growth model (Monserud 1978b used North Idaho version 2.1, whereas Inland Empire Version 4.0 was used for this paper); (2) changes have also been made in the subroutines that link the Stand Prognosis Model with the DFTM Outbreak Model, especially in the tree class compression algorithm; and (3) Monserud (1978b) used Wickman's Y-Ridge plots 1-4, whereas the examples simulated in this section are based only on plots 1-3.

Figures 8-12 illustrate the effect of varying the method for allocating first instar larvae to the tree classes at the start of the outbreak. In figure 8, the random larval allocation assumption (see the RANLARVA keyword) was used to allocate an average of 5, 8, 14, 20, and 100 first instar larvae per 1000-in^2 sample branch, using a standard deviation of 2 larvae in all cases. Only minor impacts on projected stand volume resulted when larval densities averaged 5 or less per 1000-in^2 sample branch for each tree class. Severity increased when this average density increased to 8, with 670 ft^3/acre lost in 5 years. At an average density of 14 larvae, over 40 percent of the standing volume was lost in 5 years. Increasing the average initial number of larvae from 14 to 20 resulted in a relatively small increase in the severity of the outbreak: 650 ft^3/acre more were lost in 5 years. Note the nonlinear effect on volume lost as average larval density is increased. The change in volume loss attributable to increasing average density from 8 to 14 larvae per tree class is over two times the change in volume loss due to increasing density from 14 to 20 larvae per tree class. And perhaps the highly nonlinear behavior of the DFTM Outbreak Model is best illustrated by observing the effect of increasing the average number of larvae to the highly unlikely level of 100; insect densities were so high that there was not enough new foliage to carry the population through the first two instars. Mass starvation ensued, resulting in the collapse of the simulated outbreak.

After 45 years, projected volume development following the lowest two levels of outbreak (5 and 8 larvae per tree class) illustrated in figure 8 nearly caught up with the no-outbreak volume level. However, even 50 years after the two most severe simulated outbreaks began (14 and 20 larvae), volume development was still 700 to 1300 ft^3/acre behind the no-outbreak level. Obviously, insect density at the start of the outbreak can influence the simulated stand's development far into the projection.

This figure illustrates an additional important point. Consider one of the most severe outbreaks graphed, the 14 larvae per tree class curve. Five years after the outbreak began, almost 2000 ft^3/acre were estimated to be lost. But 50 years after the outbreak began, only 700 ft^3/acre were lost (and probably less than that since any regeneration subsequent to the outbreak was ignored). If this particular stand were not scheduled for harvest for, say, 50 years, then it is misleading to tell the manager that 2000 ft^3/acre have been lost, for the stand will probably "find" much more than half of these lost cubic feet if left alone for 45 more years. The point of this admittedly oversimplified argument is that "loss" is not constant over time. Perhaps more realistic measures of loss would be either the expected number of additional years required to reach the volume anticipated at the end of the rotation if there had been no tussock moth outbreak, or the expected volume loss at the end of the scheduled rotation.

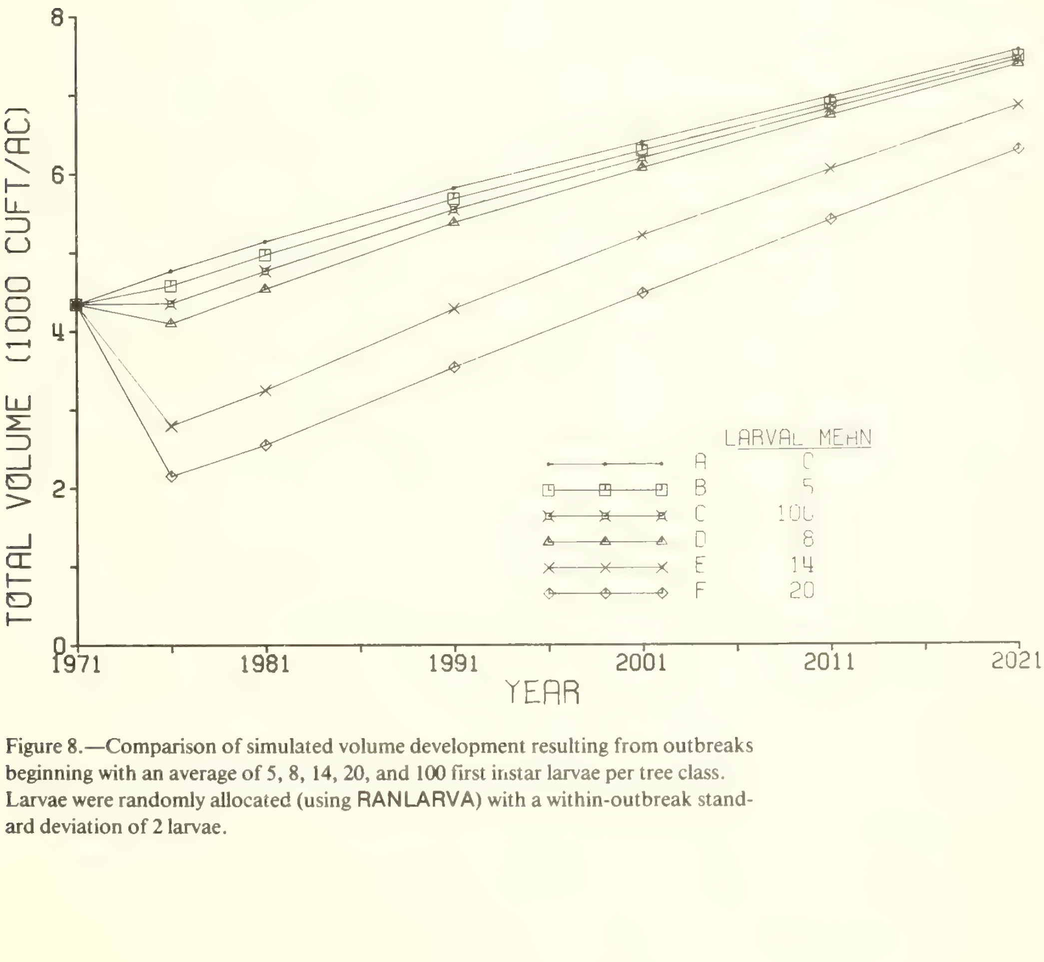

Figure 8.—Comparison of simulated volume development resulting from outbreaks beginning with an average of 5, 8, 14, 20, and 100 first instar larvae per tree class. Larvae were randomly allocated (using RANLARVA) with a within-outbreak standard deviation of 2 larvae.

The random larval allocation assumption is also used in figures 9 and 10, but with the within-outbreak standard deviation of larvae varying (Field 3 on the **RANLARVA** keyword record) rather than the average number of larvae per tree class. The average number of larvae in these simulations was 14 for figure 9, and 5 for figure 10; standard deviations of 0, 2, 4, 8, and 16 larvae per tree class were used for both figures. Examination of figures 9 and 10 indicates that the relationship between the severity of the outbreak and the variability of the larval density (judging from the standard deviation about the average level) depends somewhat on the average density of the larvae. When the average density is low (figure 10: 5 larvae per tree class), severity increases as larval variability increases; this effect is somewhat reversed when average density is high (figure 9: 14 larvae per tree class). The reason for this behavior is actually illustrated in figure 8. When the average larval density is high, the increase in severity (volume loss) on tree classes that received positive random deviates (more insects than the average) in the larval allocation procedure is more than offset by the decrease in severity on tree classes receiving equally likely negative deviates. And when larval density is low, the opposite effect occurs, for a positive deviate when randomly allocating larvae to tree classes results in much more volume loss than can be gained by an equally sized negative deviate.

The effect of allocating a fixed amount of first instar larvae to trees in three different size classes is compared next (figures 11 and 12); the deterministic larval allocation assumption (see the **DETLARVA** keyword) is used to simulate this. Recall that tree classes are sorted by average diameter into descending order before larvae are allocated deterministically. The high, medium, and low larval levels were 11, 9, and 7 for Douglas-fir sample branches and 15, 10, and 5 for grand fir, respectively; the default values of all other options were used.

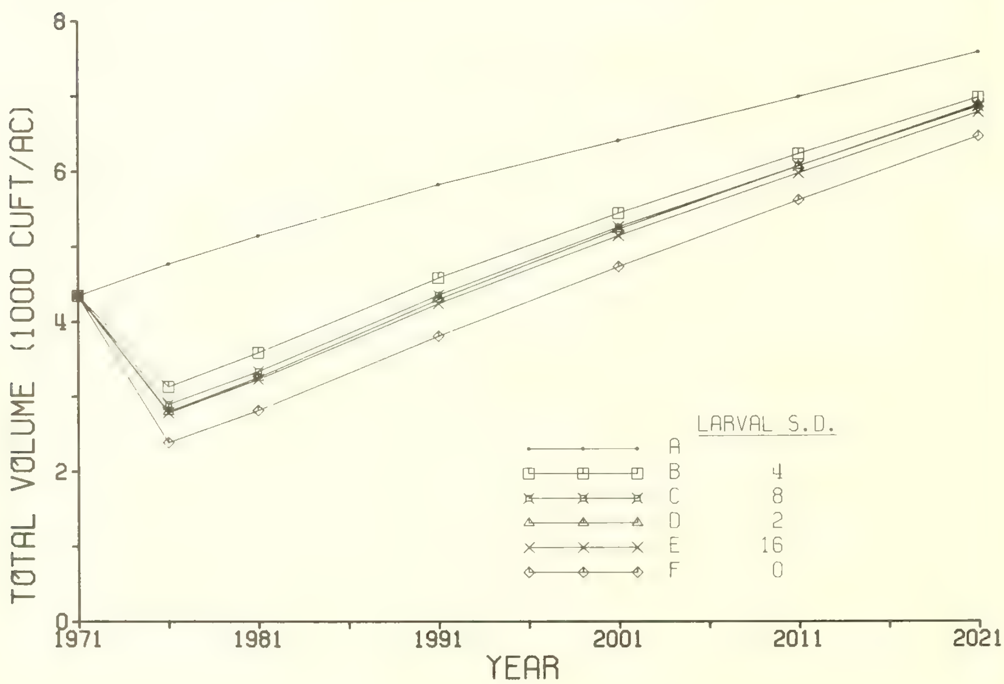

Figure 9.—Simulated volume development resulting from outbreaks beginning with an average of 14 first instar larvae per tree class. Larvae were randomly allocated with a standard deviation of 0, 2, 4, 8, and 16 larvae.

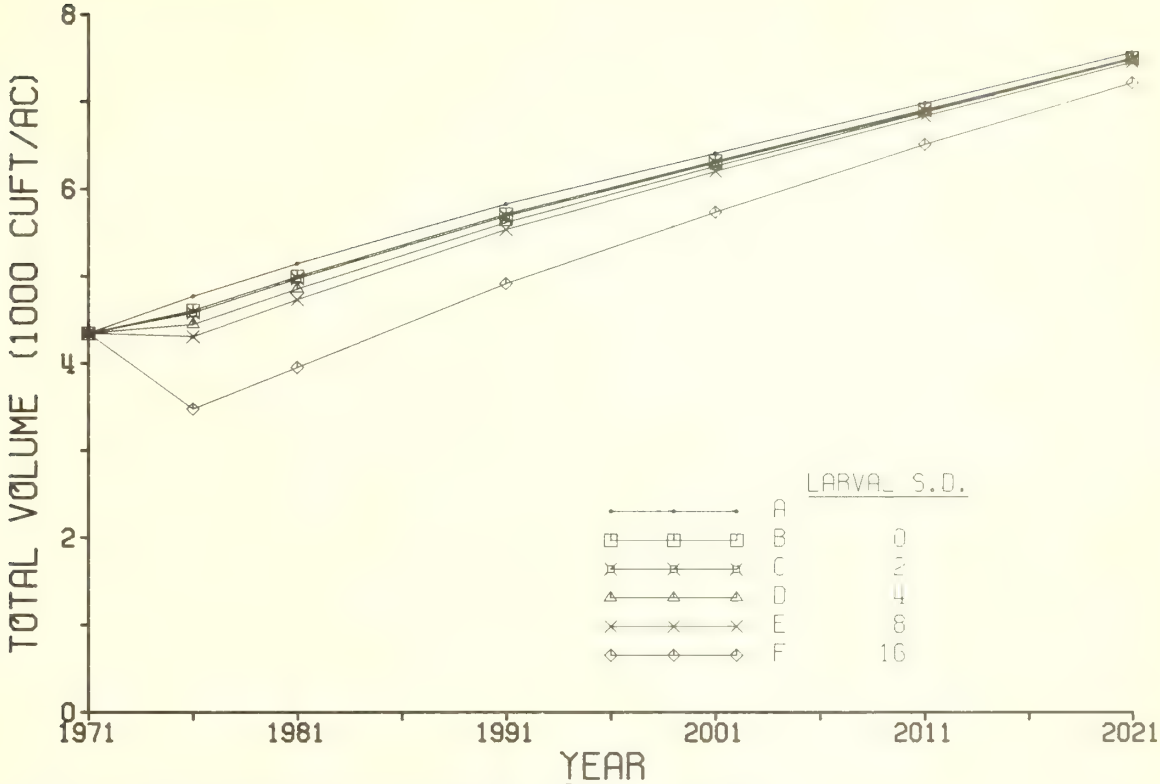

Figure 10.—Simulated volume development resulting from outbreaks beginning with an average of 5 first instar larvae per tree class. Larvae were randomly allocated with a standard deviation of 0, 2, 4, 8, and 16 larvae.

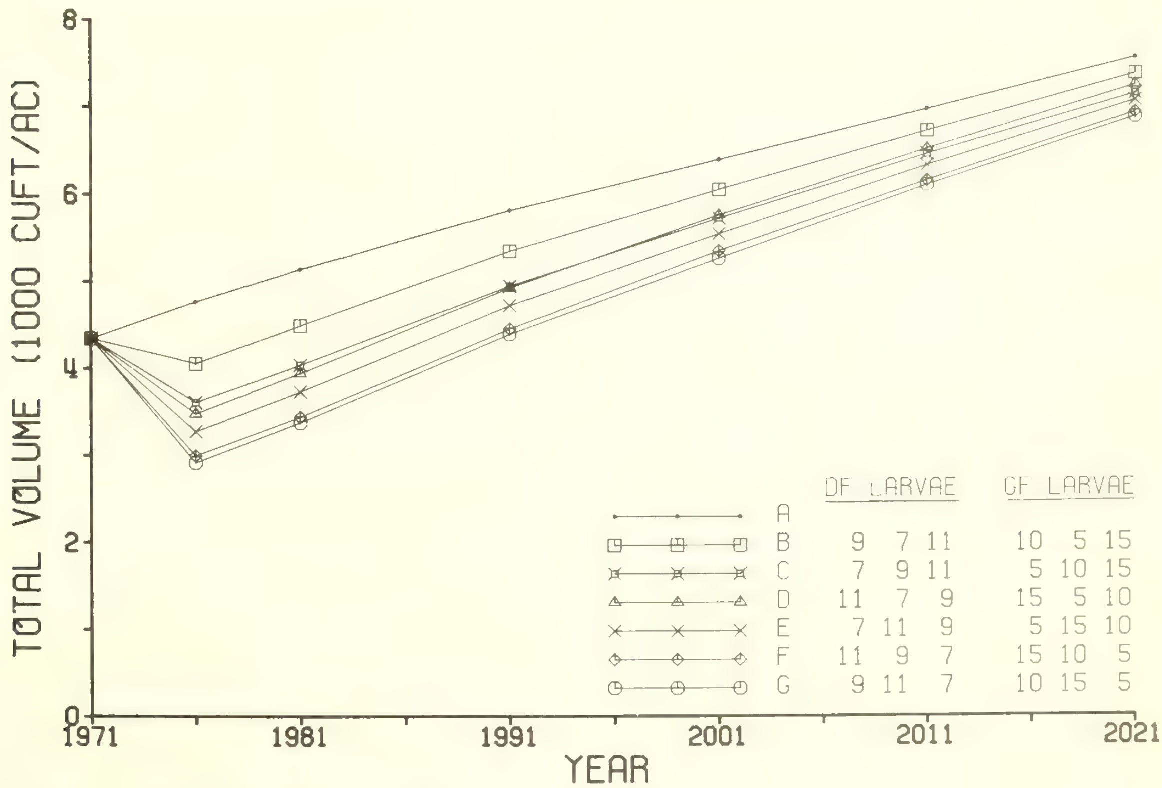

Figure 11.—Simulated volume development following outbreaks resulting from deterministically allocating three larval densities (Douglas-fir: 7, 9, 11; grand fir: 5, 10, 15) to each third of the average diameter distribution. Each outbreak resulted from the same total number of first instar larvae. Note that each tree class represented an unequal number of trees per acre.

All possible combinations of allocating these larval densities to the three diameter classes were simulated to produce figure 11. The most severe reduction in volume was obtained by assigning the high larval density to the middle third rather than the top third of the diameter distribution. This apparent anomaly occurred because the middle third of the diameter distribution represents more trees per acre (and more volume) than the upper third. In light of this, it is not surprising that the least severe reductions in volume resulted from assigning the low larval density to the middle third of the diameter distribution. Recall that the number of trees per acre each tree class represents is determined both by the original stand inventory design and the method for allocating tree records to tree classes (Field 3 on the NUMCLASS keyword record); the methods for allocating larvae to the tree classes are independent of the number of trees per tree class.

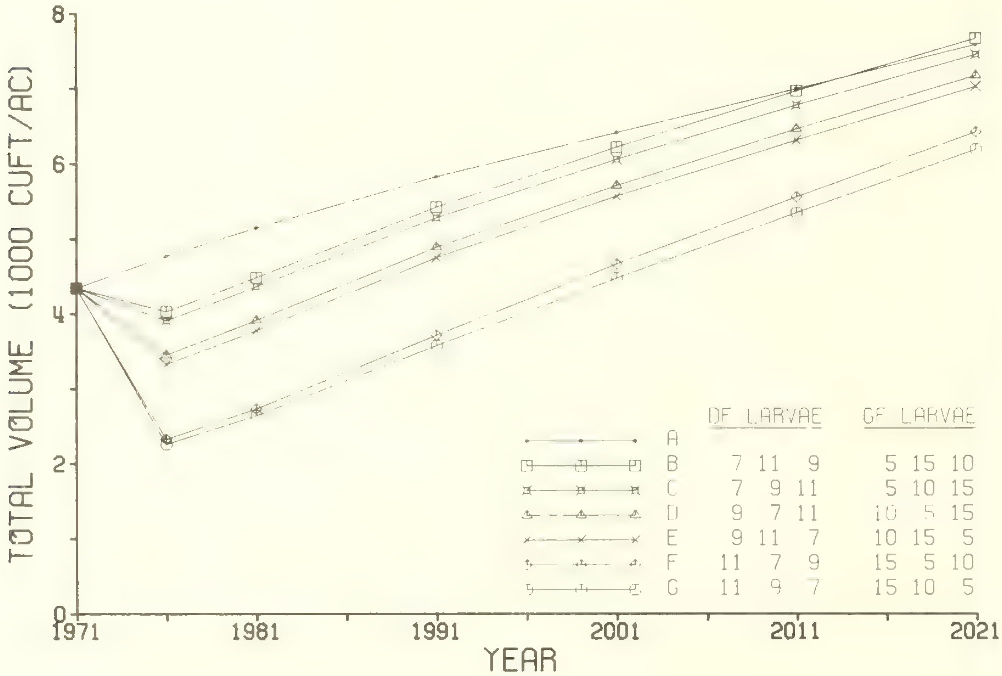

Figure 12.—Simulated volume development following outbreaks resulting from deterministically allocating three larval densities (Douglas-fir: 7, 9, 11; grand fir: 5, 10, 15) to each third of the average diameter distribution; each tree class represents approximately an equal number of trees per acre. Each outbreak resulted from the same total number of first instar larvae.

In the simulations illustrated in figure 12, larvae were allocated deterministically to tree classes exactly as they were in figure 11. For this case, however, biomass was allocated deterministically (using BIOMASS method 3 rather than the default method 4), and the successive-halving rule was used exclusively to create tree classes (Field 3 was 0.0 on the NUMCLASS keyword). These two changes resulted in an approximately equal number of tree records in each tree class, and thus the number of trees per acre in each third of the diameter distribution was roughly equal. The result of varying the allocation of a fixed number of larvae by tree size-class can be quite dramatic, as can be seen in figure 12. As expected, the most severe outbreaks (judging from volume loss) occur when the high level of larvae are assigned to the largest third of the diameter class, and the least severe outbreaks occur when this high level of insects is distributed to the lowest third of the diameter class.

This latter case is quite interesting, for the standing volume 45 years after the lightest outbreak (curve B in figure 12) is greater than in the ''no outbreak'' simulation, even though 740 ft^3/acre were killed by the tussock moth in this outbreak. Concentrating the larvae in the smaller diameter trees is apparently silviculturally similar (in this case) to a light thinning in a stand that is overstocked in the small diameter classes. Although tussock moth outbreaks invariably result in a short-term volume loss, these results indicate that some outbreaks have the potential for mimicking wise management, and being beneficial in the long

run. It is quite apparent from figure 12 that stand volume development can vary greatly, depending on the size of tree defoliated during the outbreak. Using overall stand averages for insect densities thus results in less precise estimates of volume development if the pest is differentiating between tree size classes, or redistributing more to trees of one size class than another.

The effect of varying the method of allocating foliage biomass to the tree classes is examined next (fig. 13). In this and subsequent runs, the random larvae option was used to allocate an average of 14 first instar larvae per tree class, with a standard deviation of 2 larvae. A fairly large amount of variability results from varying the foliage biomass method. This should not be surprising, for foliage biomass is the only tree characteristic important to the DFTM Outbreak Model. Note, however, that all the outbreak volume-over-time curves in figure 13 converge, except that which was produced by using BIOMASS method 2 (curve B); this method uses the deterministic biomass equations of Hatch and Mika (1978) that Monserud (1978a) concluded are poorly behaved.

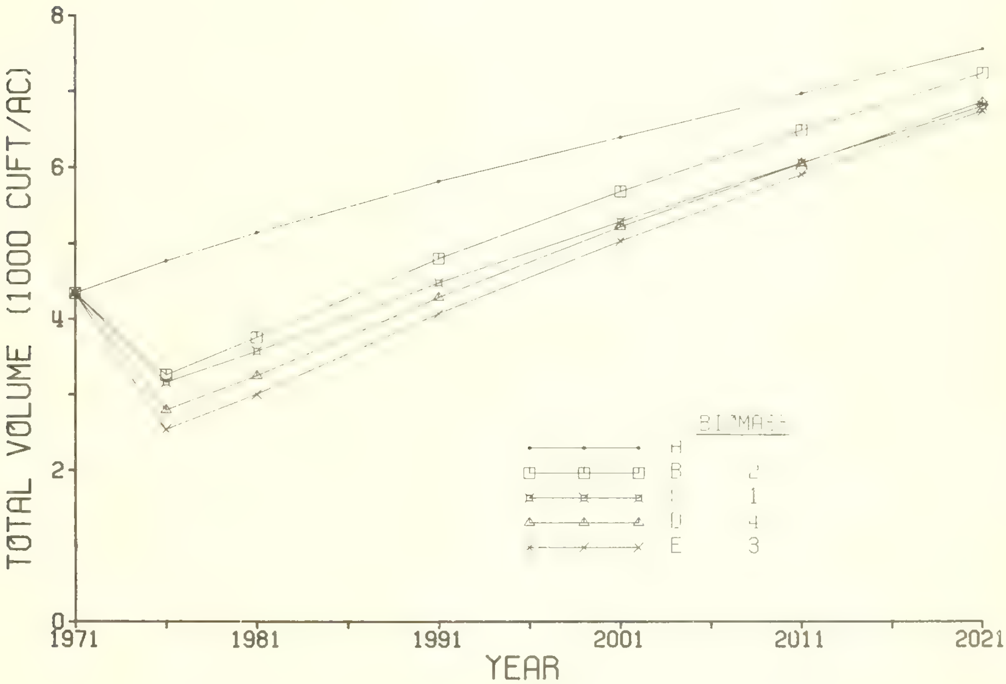

Figure 13.—Comparison of simulated volume development resulting from outbreaks that began with each of the four methods of allocating foliage to the 1000-in² mid-crown sample branch that represents a tree class. In this and all subsequent figures, the random allocation method was used to distribute an average of 14 first instar larvae per tree class, with a within-outbreak standard deviation of 2 larvae, except for figures 22 and 24. In addition, the default foliage biomass option (method 4) was used for all other figures.

Figure 14 illustrates the effectiveness of simulating various control measures for the same outbreak conditions. The "no control" curve (G) in figure 14 is the same as curve E in figure 8 and curve D in figure 13: foliage was determined by the default biomass option (method 4), and first instar larvae were assigned to tree classes randomly (average = 14, standard deviation = 2). Control treatments (especially virus) that are applied in Phase II of this simulated outbreak almost completely control the tussock moth (as far as volume loss is concerned), unless the treatment is of low efficacy (e.g., 80 percent) and applied late in

Phase II (curve C). Delaying control treatments until Phase III results in much greater variation in effectiveness. An early application of chemical control with a high efficacy (e.g., 95 percent, curve B) is quite effective in reducing volume loss, while delaying application until late in the outbreak results in almost no control even through efficacy is high (curve F). Intermediate levels of control are obtained by applying virus (curve E) or chemical controls of lower efficacy (curve D) early in Phase III. All simulated control measures had one obvious effect in common: the later the application and/or the lower the efficacy, then the greater the volume loss at the end of the outbreak.

The effect of varying salvage intensities is next shown (fig. 15). Note that the "no salvage" outbreak curve (B) is the same as the "no control" curve (G) in figure 14. The major effect of salvage appears to be a reduction in the rate of stand development; the rate of reduction increases as salvage intensity increases. Keep in mind that the volume available at the end of these 50-year projections is most likely underestimated for the heavy salvage treatments, because the current version of the Stand Prognosis Model does not yet simulate the development of seedlings that would become established subsequent to the salvage. It is apparent, however, that the time required for a simulated stand to reach preoutbreak volume levels can be lengthened considerably by increasing the salvage intensity.

In figure 16 the annual insect redistribution rate (Field 1 on the REDIST keyword record) is varied. As in previous figures, first instar larvae at the start of the outbreak were allocated to tree classes randomly with a mean of 14 and a standard deviation of 2 larvae per tree class. As expected, the severity of the outbreak increases as the insect redistribution rate is increased from 0.0 (no annual insect redistribution) to 1.0 (completely uniform redistribution of insects among tree classes). Although not illustrated, varying the redistribution rate with a higher standard deviation (namely 8) for allocating larvae to tree classes produced essentially the same results as exhibited in figure 16.

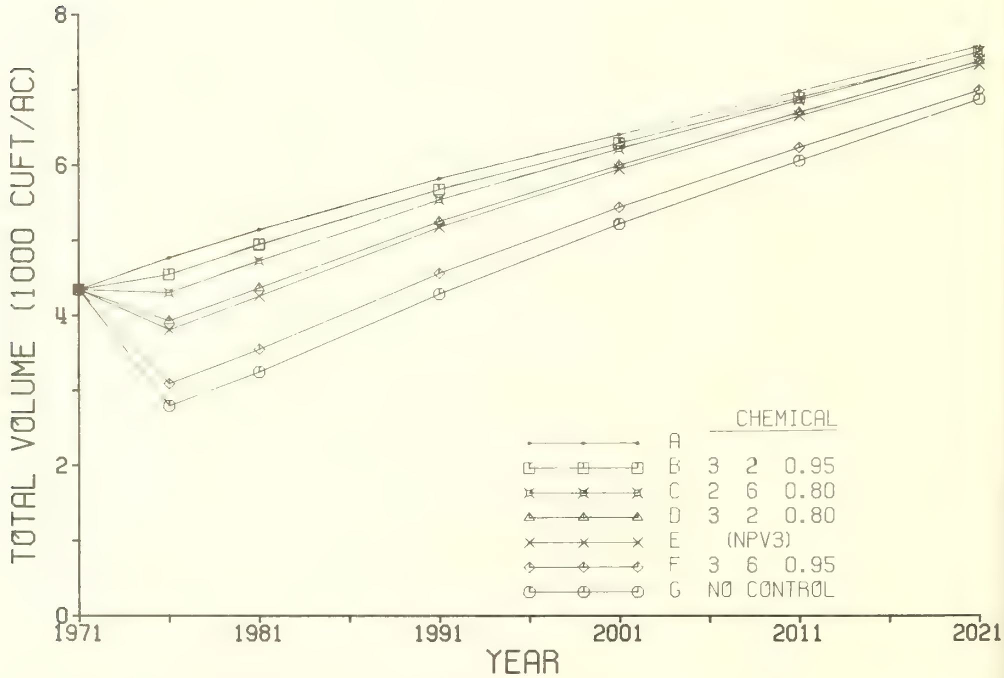

Figure 14.—Simulated volume development following application of various DFTM control measures. Virus and chemical controls applied in Phase II or III were simulated. In addition, two efficacy levels (80 percent and 95 percent) and early (instar 2) and late (instar 5) application of chemical control were considered.

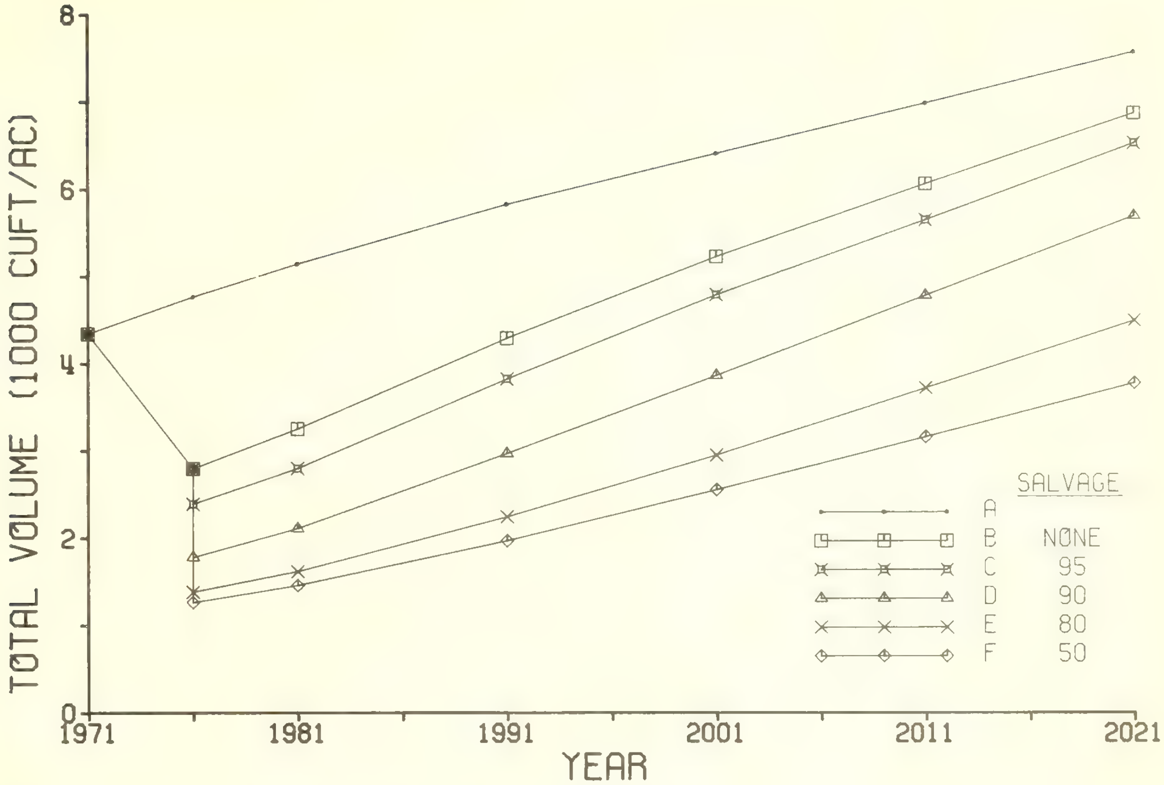

Figure 15.—Simulated volume development following various salvage intensities. Surviving trees with defoliation exceeding 95 percent, 90 percent, 80 percent, and 50 percent were salvaged. Note that an additional 1835 ft³/acre in mortality is also available for salvage in 1976.

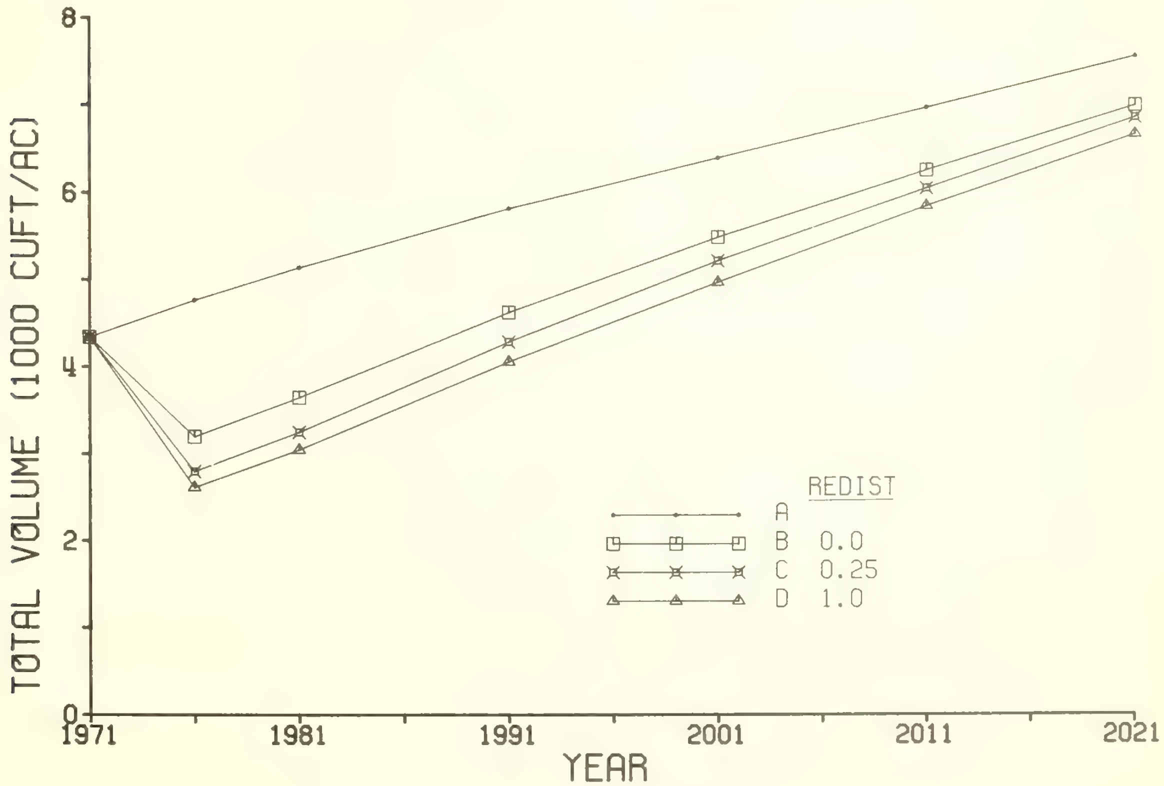

Figure 16.—Simulated volume development resulting from varying the annual insect redistribution rate during the outbreak. A rate of 0.0 results in no redistribution, and a rate of 1.0 results in perfectly uniform redistribution of insects among tree classes; the default value is 0.25.

In figures 17 though 20, the factors that affect the compression of the list of trees into tree classes are varied. The WEIGHT keyword is used to specify the relative importance of the two foliage biomass variables (i.e., percentage new foliage and total foliage biomass of the sample branch). Curve C in figure 17 was produced by the default values for the WEIGHT keyword parameters: percentage new foliage and total foliage biomass both had a weight of 1.0 (i.e., percentage new foliage was considered just as important as total foliage biomass). Most combinations of WEIGHT keyword parameters produced simulated results that are bracketed by the two extremes: giving percentage new foliage no weight (curve B), and giving total foliage biomass no weight (curve F) in the tree class compression routine. An examination of figure 17 reveals that varying the parameters of the WEIGHT keyword resulted in minor changes in predicted volume for this particular stand. This is primarily a result of the method of allocating the foliage biomass to the trees (method 4 in this case). As long as there is a strong correlation between percentage foliage biomass and total foliage biomass, then changing the parameters on the WEIGHT keyword should have a minor effect on the simulated outbreak.

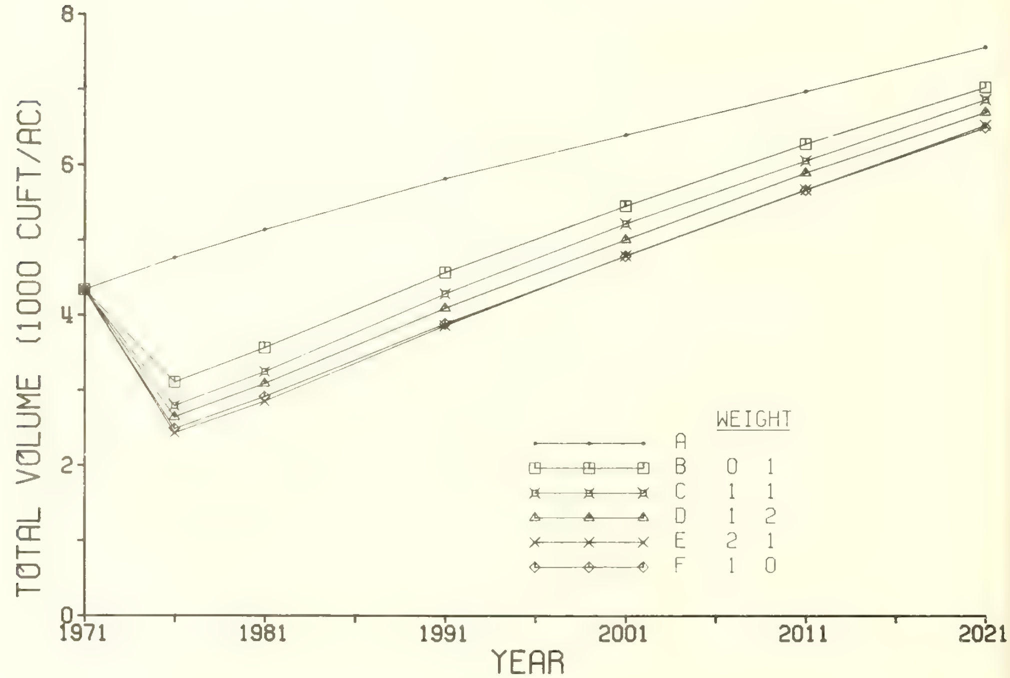

Figure 17.—Simulated volume development resulting from varying the parameters on the WEIGHT keyword that determine the importance of percentage new foliage relative to total foliage biomass in the tree class compression algorithm.

The number of tree classes (the first two parameters of the NUMCLASS keyword) used to represent the list of trees in the DFTM Outbreak Model is next varied (fig. 18). Observe that the default values of 20 tree classes per host species (curve C) result in a volume-over-time curve that is quite close to the curve produced by using 50 tree classes per species (curv D). Based on numerous projections, 20 tree classes per species does appear to provide a good approximation to the actual tree list. Note that using 5 tree classes per species (curve B) resulted in a volume-over-time curve almost coincident with the default 20 tree class per species curve (C). It would be incorrect, however, to infer that using 5 tree classes per species is as accurate as using 20 (although it is true in the example summarized by figure 18). Generally, using less than 10 tree classes per species results in quite erratic behavior, an is not recommended.

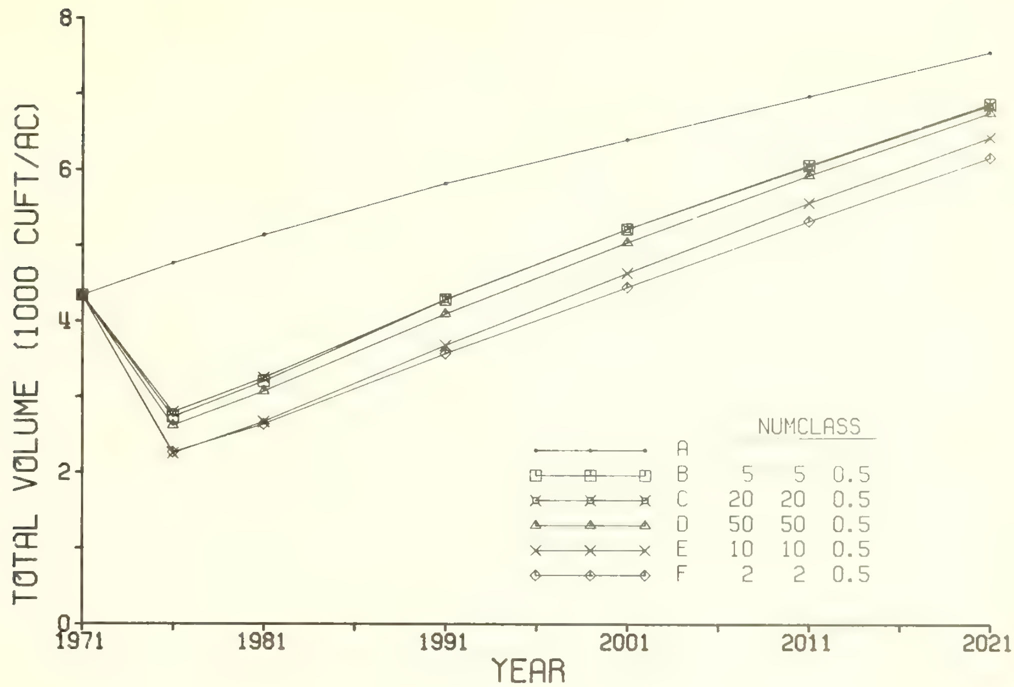

Figure 18.—Simulated volume development resulting from varying the number of tree classes into which the list of trees is compressed before calling the DFTM Outbreak Model. Half of the tree classes were created using the (first) maximum difference algorithm, and the remainder were created by the (second) successive halving compression algorithm.

The third parameter (temporarily call it PROP) on the NUMCLASS keyword record specifies the proportion of tree classes to be determined by the first tree class compression algorithm (the maximum difference algorithm); the remainder are created using the second (successive halving) algorithm. To see the effect of varying PROP as the number of tree classes per species is also varied, compare figure 19 (using PROP = 0: the successive halving algorithm) and figure 20 (using PROP = 1: the maximum difference algorithm) with figure 18 (PROP = 0.5, the default). It is apparent that exclusive use of the maximum difference algorithm (fig. 20) results in large variation in the consequent simulated outbreak as the number of tree classes is varied; the volume-over-time curve does not stabilize until the number of tree classes gets close to 50 per species. In contrast, the second compression algorithm (used exclusively in figure 19) produces stable results with much fewer tree classes (and less computing cost).

Results obtained from simulated outbreaks that utilize the pseudorandom number generator (Marsaglia and Bray 1968) are obviously conditional upon the sequence of random numbers used in the various calculations. The amount of variability in a given simulation that is due to the random number sequence is not at all obvious, however. By reseeding a given simulation several times (with the RANNSEED keyword) and holding all other input conditions constant, this "random" variability can be isolated and assessed.

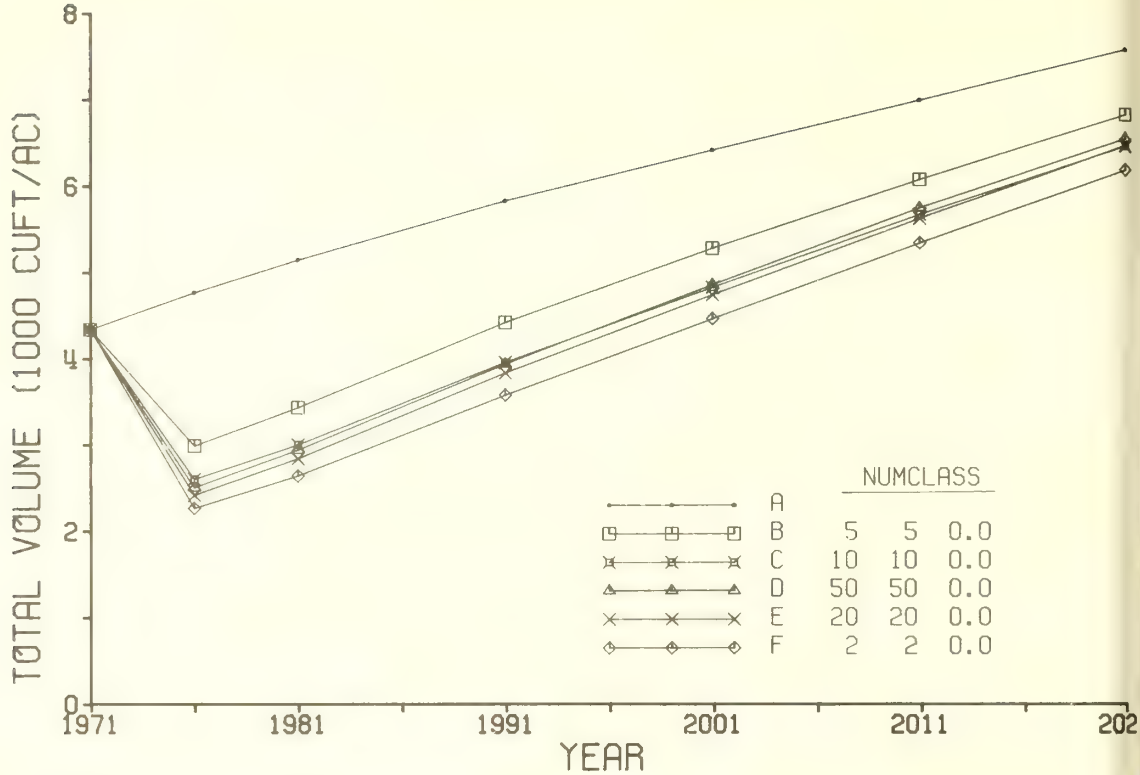

Figure 19.—Simulated volume development resulting from varying the number of tree classes to be created by exclusively using the successive halving algorithm (parameter 3 on the NUMCLASS keyword equals 0.0).

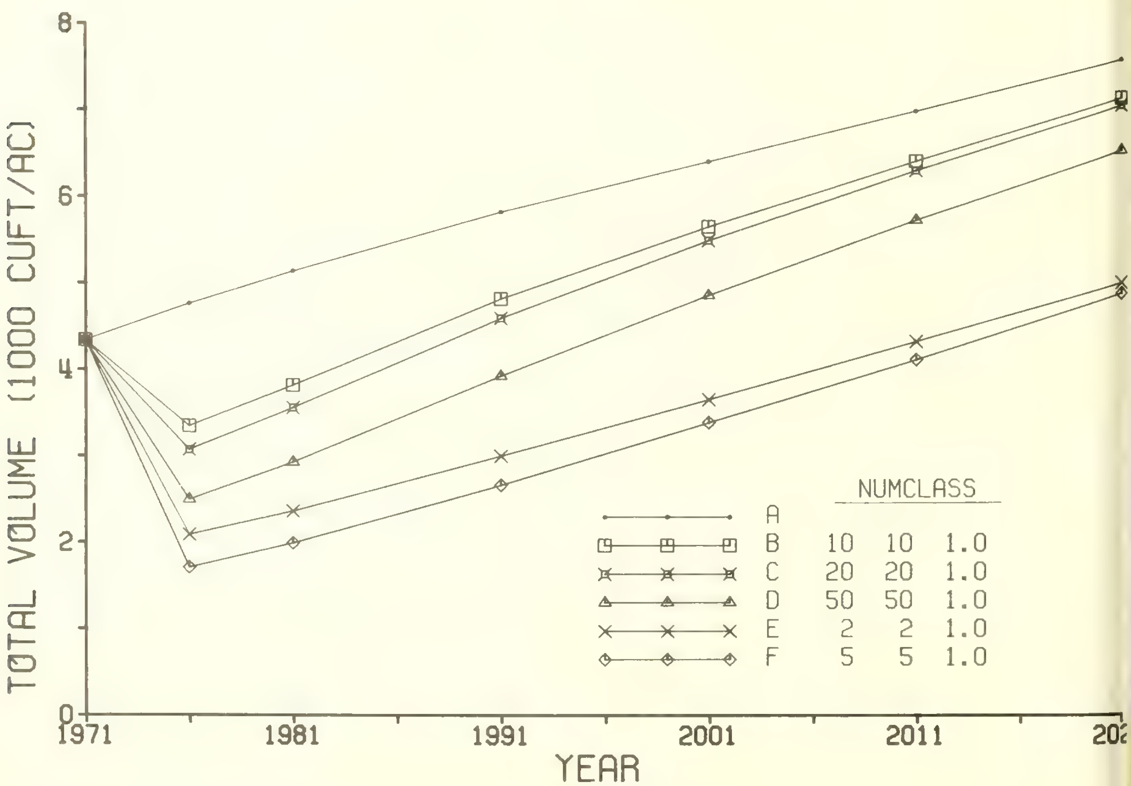

Figure 20.—Simulated volume development resulting from varying the number of tree classes to be created by exclusively using the maximum difference algorithm (parameter 3 on the NUMCLASS keyword equals 1.0).

An indication of the variability associated with the random larval allocation option is illustrated in figures 21 and 22. In figure 21, an average of 14 first instar larvae were randomly allocated to each tree class, with a standard deviation of 2 larvae; in figure 22 the standard deviation was increased to 8 larvae. Only the seeds of the random number generator were varied for the groups of simulations displayed in figures 21 and 22. As expected, the variability in simulated volume increases with the standard deviation of the distribution that the random number generator is being used to produce. Keep in mind that the default biomass option (4) contains an additional source of random variation in figures 21 and 22, as does the algorithm for assigning top-kill damage to individual trees.

When working with a simulation model containing varying degrees of random variability, there is always a risk that one simulation from a given set of initial conditions may be atypical. A good way to deal with this random variability is to generate replicate simulations (varying only the random number seeds) until the mean of the variable of interest (total volume over time in the examples in this section) is determined with acceptable accuracy; the user must of course consider the trade-off between the increase in both cost and precision to be obtained from additional replicate simulations in determining what level of accuracy is acceptable. An even better way to deal with the variability in the simulated system is to consider both the estimated mean and variance of the variable of interest in decision-making. For example, output from replicate runs of the simulation model can be used to estimate the probability that a given critical value (say, 4,000 ft^3/acre lost) will be exceeded in deciding whether or not to apply a control measure.

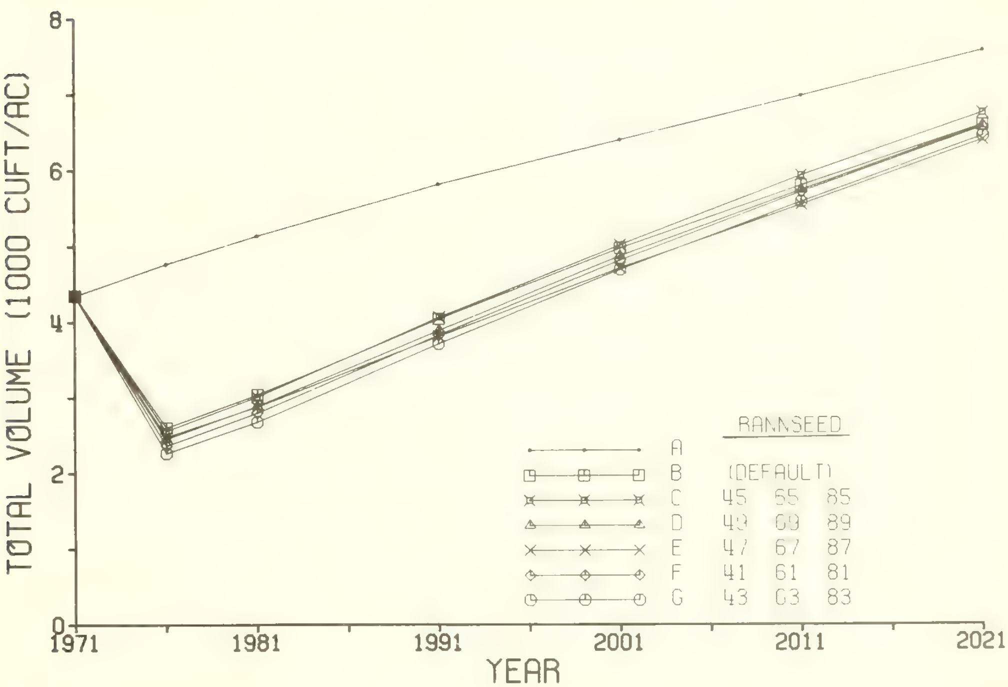

Figure 21.—Simulated volume development resulting from varying the sequence of random numbers used by the tussock moth related routines in the combined model. First instar larvae were allocated randomly to tree classes with an average of 14 and a standard deviation of 2 larvae.

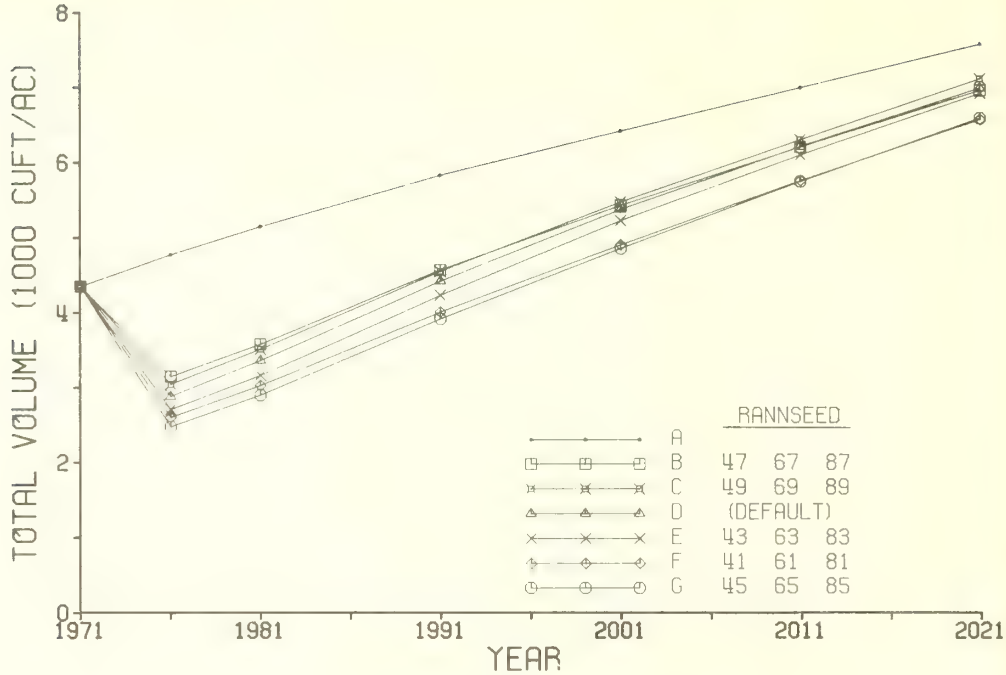

Figure 22.—Simulated volume development resulting from varying the sequence of random numbers used by the tussock moth related routines in the combined model. First instar larvae were allocated randomly to tree classes with an average of 14 and a standard deviation of 8 larvae.

Implications for Modeling Repeated Outbreaks

The portion of the Combined Model where unpredictable variation is most evident is in the algorithms that stochastically control the timing and occurrence of outbreaks (see the RANSCHED, RANSTART, and PROBMETH keywords). To illustrate (fig. 23), consider the following simulation. Regional outbreaks were scheduled with a probability of occurrence of 0.1, given that a 30-year waiting time had elapsed since the last regional outbreak. Whether or not the subject stand would be included in a regional outbreak was also determined stochastically, based on the stand's susceptibility to tussock moth. First instar larvae were allocated randomly to the tree classes (average = 14, standard deviation = 2); note that long-term larval density was held constant (between-outbreak standard deviation = 0.0 larvae). Default values were used for all other keywords and parameters. Five simulations were run; the first (fig. 23, curve B) used the default seeds for the random number generator, and the next four (fig. 23, curves C-F) used different random number generator seeds.

It is clear from figure 23 that the variability associated with this stochastic outbreak option is immense. Furthermore, it is quite unlikely that any given simulation using these same initial conditions could be called typical. If one is interested in estimating expected volume development over time resulting from these initial conditions, then it is almost essential to calculate the "average outbreak" volume curve (G).

Figure 23 can also be examined in a different light. Recall that the large variability exhibited by curves B-F results from changing only the sequence of random numbers. It follows that any manipulation of the stand—no matter how minor—that in effect alters the sequence of random numbers may produce results comparable to reseeding the random number generator. Thus the projected yields for two stands that are very similar—but not identical—could be quite different if severe but infrequent stochastic outbreaks (such as in figure 23) are being simulated. The importance of replicating a given simulation with different random number seeds cannot be overemphasized, especially when using the stochastic outbreak feature.

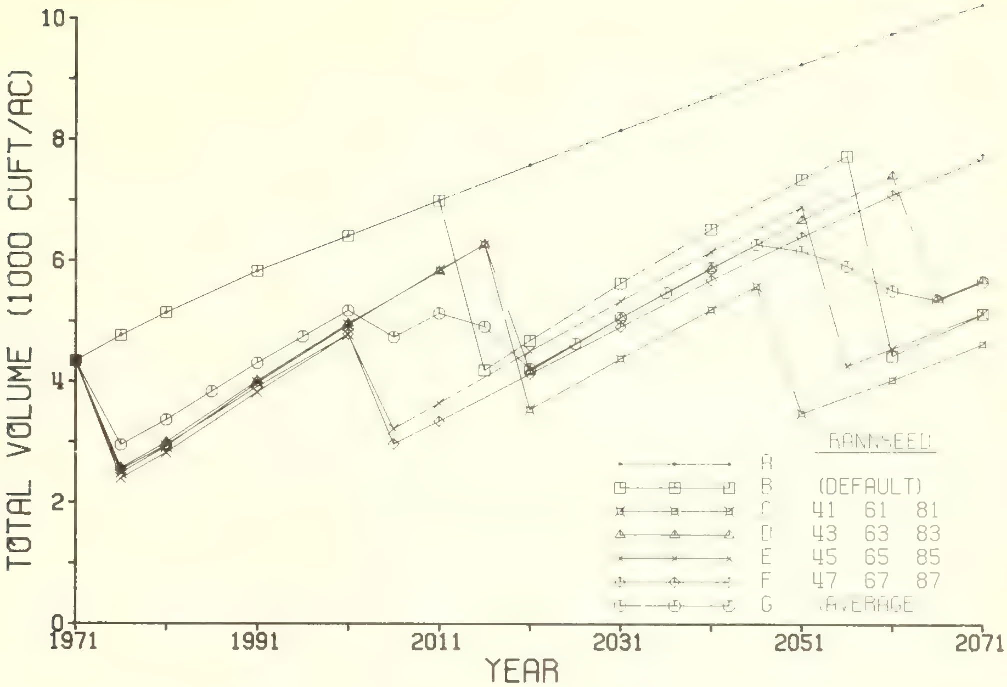

Figure 23.—Five replicates of simulated volume development resulting from varying the sequence of random numbers used by the tussock moth related routines in the combined model. Regional outbreaks were scheduled stochastically with a regional probability of outbreak of 0.1 given that a minimum of 30 years had elapsed since the last regional outbreak; whether or not the sample stand was included in the regional outbreak was also determined stochastically. The average outbreak curve G is obtained by averaging the five replicates (B-F).

Figure 24 illustrates six such average outbreak volume curves, with both the frequency and severity of the outbreaks being varied. As in the previous figure, the actual timing of outbreaks was stochastically determined by using the RANSCHED and RANSTART keywords, and larvae were randomly allocated to tree classes. Three levels of severity were simulated: an average of 4, 8, and 14 first instar larvae per tree class were allocated with a within-outbreak standard deviation of 2 larvae (roughly corresponding to light, moderate, and heavy severity, respectively). As in the previous figure, long term larval density was held constant (Field 4 on the RANLARVA keyword record was 0.0). For each of these levels of severity, both frequent and infrequent outbreaks were scheduled: the RANSCHED parameters for the frequent outbreaks were 7 years minimum time between outbreaks with a subsequent annual probability of regional outbreak of 0.3; the corresponding parameters for the infrequent outbreak schedule were 30 years and 0.1, respectively. The expected value of the time between outbreaks was thus 9-2/3 years for the frequent outbreak simulations and 39 years for the infrequent outbreaks. For each of the six combinations of outbreak severity and frequency, five replicates were simulated (by varying the seeds of the random number generator). Note that each curve graphed in figure 24 is the average of these five replicates. The default values for all other keywords were used.

For the range of conditions examined in this example, average volume lost (due to tussock moth) over time increased as either the severity (i.e., the number of larvae at the start of an outbreak) or the frequency of the simulated outbreak was increased; this is a rather predictable result. What is not very predictable, however, is the relative importance of frequency versus severity of outbreaks on long-term volume yields. It is quite difficult to make generalizations in this regard, for figure 24 contains both examples of frequency of outbreaks being a more important factor in explaining volume loss than the number of larvae at the start of an outbreak (compare cuves E and F) and vice versa (compare curves C and F).

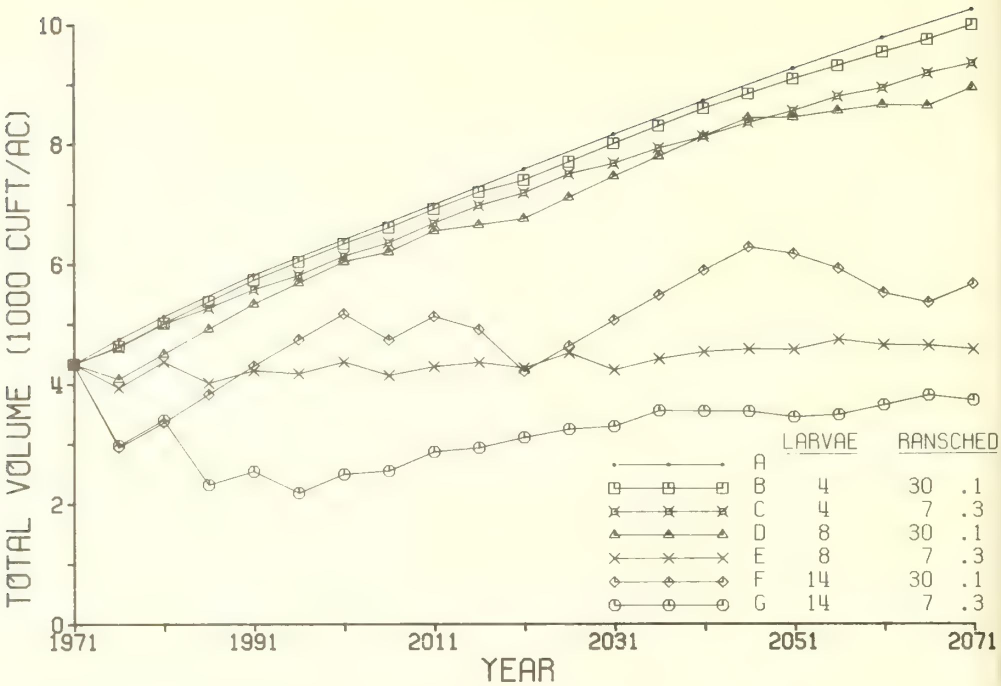

Figure 24.—Average simulated volume development resulting from varying the frequency of outbreaks for three different larval densities. Each outbreak curve (B-G) is the average of five simulations resulting from different random number sequences. The between-outbreak larval standard deviation was zero in these simulations.

Furthermore, there are probably many combinations of these factors that will produce the same amount of volume at a given age or time. For example, curves C and D are quite close together, even though outbreaks in curve D began with twice as many larvae as those in curve C, and the average interval between outbreaks is 30 years longer in curve D than in curve C. Such results have implications for hazard or risk rating systems. An accurate hazard rating scheme should obviously consider the long-term probability of outbreak as well as the likely severity of individual outbreaks. It is the joint effect of frequency and severity of outbreaks that determines the expected loss over time due to tussock moth.

The amount of variability associated with each of the average outbreak curves graphed i figure 24 decreased if either the severity of the simulated outbreaks was decreased or the fr quency of the outbreaks was increased. Thus the average outbreak curve in figure 24 with the most variability is F; note that this curve is the same as curve G in figure 23.

An important point can be made regarding the simulations summarized in figure 24: a few of the curves are likely unrealistic. For example, it is highly unlikely that the combination of severe and frequent outbreaks averaged to produce curve G (and probably curve E would ever occur in the same stand, although outbreaks have occurred as frequently in the Palouse Range and more severely in the Blue Mountains. Even though the same stand ma be involved in repeated outbreaks, it is unlikely that such outbreaks would be equally seve and repeatedly start with the same larval density. The random larval allocation method co tains an option that allows average larval density to vary from outbreak to outbreak. This option was used to produce figure 25: the between-outbreak standard deviation was set at 6.0 larvae (Field 4 on the RANLARVA keyword record) and all the simulations that were used to produce figure 24 were rerun. Thus figure 25 illustrates six average outbreak curve (again based on five replicates per curve) with both within- and between- outbreak severit (i.e., larval density) as well as outbreak frequency varying.

The major difference between figures 24 and 25 is that outbreak frequency is far more i portant when the between-outbreak larval standard deviation is moderately large (namely 6 larvae in fig. 25). All three of the "frequent" outbreak curves in figure 25 (namely C, E and G, with an expected interval between outbreaks of 9.7 years) were below the "infrequent" outbreak curves (B, D, and F, with 39 years the expected interval between out-

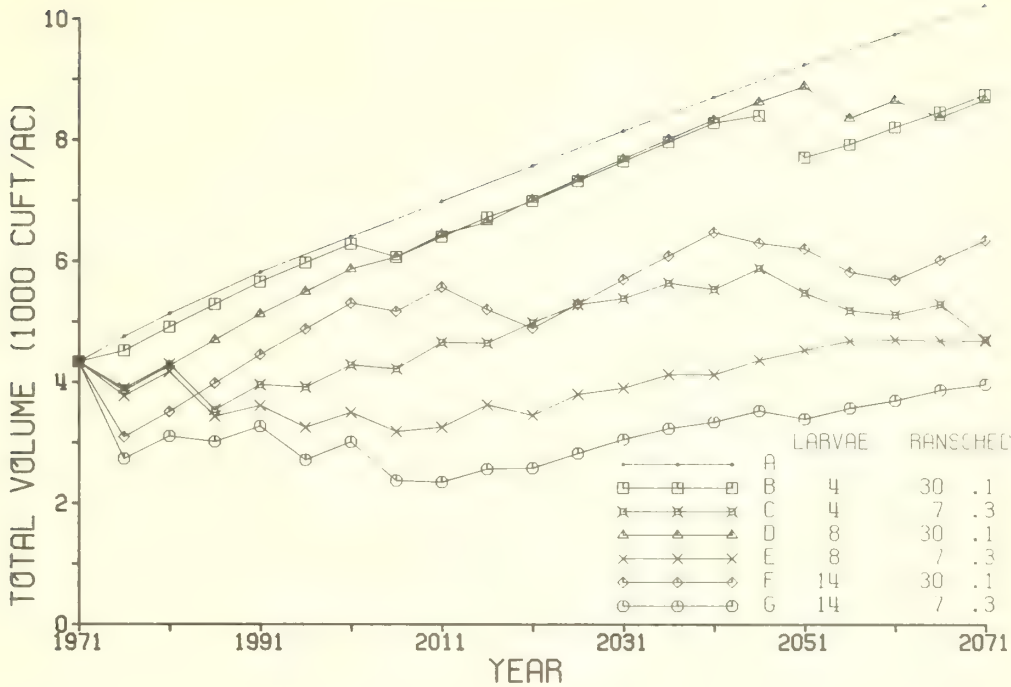

Figure 25.—Average simulated volume development resulting from varying both the frequency and the severity of the outbreaks. All simulations that produced figure 24 were rerun after raising the between-outbreak standard deviation to 6.0 larvae (Field 4 on the RANLARVA keyword record). Each outbreak curve (B-G) is the average of five simulations resulting from different random number sequences.

breaks). It may seem surprising that even curve C (frequent outbreaks with mean larvae = 4) is below curve F (infrequent outbreaks with mean larvae = 14); the reason is straightforward, however. With frequent outbreaks occurring four times as often as infrequent outbreaks, the chances of getting a severe outbreak (e.g., mean larval density = 14) are greater than 1 in 4 when the between-outbreak standard deviation equals 6 larvae, even though long-term mean density is only 4 larvae.

A final point suggested by both figures 24 and 25 concerns the use of expected yields (i.e., stand volume over time) in forest management planning. In an area where tussock moth has historically been a factor affecting stand development, it is probably overly optimistic to anticipate volume yields indicated by the "no outbreak" curve. Although it may be difficult to state with confidence which "outbreak" curve is most likely, almost all possibilities will predict less future volume than the "no outbreak" curve. The Combined Stand Prognosis/DFTM Outbreak Model has potential to reduce this bias associated with projecting future volume yields in stands susceptible to tussock moth.

The features of the Combined Model that allow both the frequency and severity of outbreaks to vary stochastically in multiple-outbreak simulations were added with hopes of making long-term projections more realistic. Unfortunately, there is little information indicating how the severity (i.e., number of larvae) of an outbreak is distributed over time, just as there is little—if any—information available describing the probability of stand outbreak for many different outbreak periods. Because of this dearth of knowledge, it was our objective to give the user considerable flexibility in stating assumptions regarding long-term interactions between the tussock moth and the stand being managed. The ultimate solution, of course, would be the development of a tussock moth population model that would be truly dynamic; this would eliminate the need for the Combined Model to predict the probability of outbreak, for the construct "outbreak" would then become an unnecessary artifact.

The numerous simulations graphed in this section were intended to serve merely as examples of model behavior rather than as definitive statements that will hold in all cases or for all stands, although some generalization from a number of the figures would be warranted. Our hope is that the potential user will have a greater appreciation for the scope and versatility of the Combined Model after viewing the numerous scenarios that can be simulated.

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APPENDIX A

Example Runstream

The following batch runstream (job control language and input data) produced the output displayed in figures 3-7. The simulation was produced on the Amdahl 470 V/8 computer at Washington State University Computing Services Center, Pullman, Washington.

```
//DFTM JOB (,,10),'F3T7',MSGLEVEL=(1,1)
//PROCLIB DD DSN=GINDX.Y1978.USFS.PROCLIB,DISP=SHR
//F3T7 EXEC GRG04,TIME=(,30),MEMBER=TMNIG4,MODLIB='T.LOADMOD'
//FT04F001 DD DSN=GINDX.Y91.DFTMFIGS,
// DISP=MOD,UNIT=,SPACE=(TRK,(30,5))
//FT02F001 DD DSN=GINDX.Y5812.MAC.STANDLIB(WICK123),DISP=SHR,
// LABEL=(,,,IN)
//FT10F001 DD SPACE=(TRK,(40,20)),UNIT=SYSSCR,              JODFTM
//             DCB=(LRECL=133,BLKSIZE=19019,RECFM=FB)
//SYSIN  DD *
TREEFMT
(16X,I3,14X,F2.0,I1,2X,A3,F3.1,F2.1,T47,F5.1,T1,2F3.1,T57,I1,T1,I2,T59,2I1)

STDIDENT
YRID-123     BAMAX = 220  -- RUN WICKMANS Y-RIDGE PLOTS WITH VERSION 4.0
BAMAX         220.
MGMTID
F3T7
ECHOSUM
STDINFO            05         520        50         5         1         40         70
INVYEAR          1971
DESIGN                        50        999        20
NUMCYCLE            6
TIMEINT            1.          5.
TIMEINT            2.          5.
DFTM
RANSCHED          30.          .1
RANSTART
RANLARVA           1.         14.         2.
RANLARVA           2.         14.         2.
RANNSEED          49.         69.        89.
SALVAGE           90.
END
TREEDATA
PROCESS
STOP
```

APPENDIX B

Program Availability

Potential users of the Combined Stand Prognosis-DFTM Outbreak Model should contact the Methods Applications Group[5] for further information. A version of the Combined Model has been converted to the USDA Ft. Collins Computer Center (which uses the UNIVAC 1100 series) for use by the public. Users desiring a copy of the source code (which is standard FORTRAN IV) should also contact the Methods Application Group.

Users should note that the version available on the USDA computer at Fort Collins, Colo., will not duplicate exactly the examples published in this paper. This variance is the result of the machine-specific characteristics of the random number generator (Marsaglia and Bray 1968). The UNIVAC 1100 at Fort Collins will produce different random numbers than the Amdahl 470 V/8 (which uses an IBM operating system) at Washington State University, Pullman—where the research and development version of the Combined Model resides.

---

[5]Address: Methods Application Group
Forest Pest Management
State and Private Forestry
USDA Forest Service
Suite 350 Drake Executive Plaza
2625 Red Wing Road
Fort Collins, Colorado

Monserud, R. A.; Crookston, N. L. A user's guide to the combined stand prognosis and Douglas-fir tussock moth outbreak model. Gen. Tech. Rep. INT-127. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1982. 49 p.

Documentation is given for using a simulation model combining the Stand Prognosis Model and the Douglas-fir Tussock Moth Outbreak Model. Four major areas are addressed: (1) an overview and discussion of the combined model; (2) description of input options; (3) discussion of model output, and (4) numerous examples illustrating model behavior and sensitivity.

KEYWORDS: *Orgyia pseudotsugata,* DFTM, simulation, modeling, growth and yield, defoliation effects, growth projection

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Fire-Climate Zones of Coastal Alaska

Arnold I. Finklin

THE AUTHOR

ARNOLD I. FINKLIN is a meteorologist at the Northern Forest Fire Laboratory. Specializing in climatology, he is currently with the Fire Effects and Use Research and Development Program. Previous assignments at this location were with Project Skyfire and the Fire in Multiple Use Research, Development, and Application Program. He received a bachelor's degree in meteorology at New York University, spent some years as a research aid at the University of Chicago, and received a master's degree in atmospheric science from Colorado State University, Fort Collins, before joining the Laboratory in 1967.

RESEARCH SUMMARY

This report presents a method for delineating fire-climate zones or areas; application is to coastal Alaska (Forest Service, Region 10). The method uses a multiple regression relationship calculated between a fire-danger parameter and simple climatic averages. The basic principle is to relate the zones to wildfire potential, utilizing data that provide maximum areal coverage. In the present case, the climatic averages were those of rainfall and daily maximum temperature for the May-August fire season. Fire danger was represented by the average seasonal number of days reaching a particular threshold value of the former Buildup Index. The regression, based on data from 18 stations, had a high statistical significance level. It was applied, as a series of curves, to the climatic averages at about 100 additional stations to give estimates of the fire-danger parameter. Fire-climate classes, comprising the fire-climate zones, were defined on the basis of this parameter.

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United States
Department of
Agriculture

Forest Service

**Intermountain
Forest and Range
Experiment Station
Ogden, UT 84401**

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Fire-Climate Zones of Coastal Alaska

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INTRODUCTION

The extensive forested areas of coastal Alaska (Forest Service, Region 10) have in the recorded past experienced generally minor wildfire occurrence, particularly when compared with that in mainland (interior) Alaska and the lower 48 United States. The maritime influence on the general climate is an obvious tempering factor with respect to fuel moisture, although large spatial differences do occur. Moreover, there is a near absence of lightning activity; wildfire ignition is thus confined, with rare exceptions, to locations of human presence.

Fire-management planning in this region, nevertheless, is presented with a somewhat difficult problem (Noste 1969). Severe burning conditions have occasionally occurred in the past few decades, even in normally wet areas. Thus, while the fire load is usually light, a capability must exist for handling the exceptional situations. A continuing expansion in the human presence, through recreational and logging activities, threatens to bring a more serious fire problem in the future. Contributing, also, would be the accumulating masses of untreated logging slash, which can dry quickly during recurring spells of warm, dry weather.

Fire-management planning has sought to concentrate attention on those areas where the wildfire potential, as influenced by climate, is greatest. Toward this policy, three broad fire-weather zones were devised in Region 10.[1] Though fire danger is monitored, less planning effort is expended with increasing wetness of climate. The present report results from a need expressed for further development and refinement of a fire-danger climatology. It is a condensed, updated version of a preliminary office report.[2] The purpose here is to present a method of defining fire-climate classes, employing a parameter of fire danger and simple climatic averages in a multiple regression. These classes are then applied in delineating fire-climate zones for coastal Alaska.

[1]U.S. Department of Agriculture, Forest Service, Revision of R-10 fire danger rating. On file at USDA Forest Service Regional Headquarters, Juneau, Alaska.

[2]Finklin, Arnold I. 1977. Fire-season climatic zones of coastal Alaska. Office report on file at Northern Forest Fire Laboratory, Missoula, Montana.

REVIEW OF RELATED WORK

Fire-climate zones or areas have been the subject of several specific studies in the past decade. Their use is included in proposals (Reifsnyder 1978) addressed to worldwide interests in fire management.

"Fire-season climatic zones" were delineated for mainland (interior) Alaska by Trigg (1971). A mosaic containing 25 zones, based on 16 climate-description classes, was developed. The climate classes were derived from modified Thornthwaite precipitation effectiveness and temperature efficiency indices, computed for a 6-month season. The basic input data were monthly precipitation and average daily maximum temperature at 48 stations.

"Fire-climate zones" were delineated for Arizona and New Mexico by Fosberg and Furman (1973). These were based on values of an adjusted equilibrium moisture content (e.m.c.) of the fine fuel complex. The e.m.c. was calculated by regression equations using air temperature and relative humidity, applied to afternoon observations at 60 stations. This method does not appear feasible for the coastal Alaska region; one reason is the wide spatial separation between stations observing relative humidity.

"Forest fire weather zones" were drawn for Canada (Simard 1973), based on increments of average June-August values of the Canadian Forest Fire Weather Index (Canadian Forestry Service 1970). These increments were related to a geometric progression of calculated fire intensity. The weather input for the index is the noontime temperature, relative humidity, windspeed, and the preceding 24-hour rainfall.

Returning to coastal Alaska, fire danger was analyzed for the region by Trigg and Noste (1969), utilizing Buildup Index (BUI) and Spread Index values (Nelson 1964) for a

10-year period, 1956-65. The indices (part of the former National Fire-Danger Rating System) were computed for 11 airport stations and a lighthouse station. Noste (1969) found a relationship between these indices and size class of acreage burned. As indicated earlier, three fire-weather zones were defined for this region (see footnote 1). The zones were characterized according to April-July average precipitation and the average number of days with BUI as high as 30 and 60. The BUI data were from the above 12 stations plus fire-weather stations with shorter records. A BUI value of 30, it was said, could cause suppression problems for a fire in logging slash; at a value of 60, a fire in uncut timber would also be a problem.

DESCRIPTION OF THE REGION; FIRE OCCURRENCE

The geographic region referred to here as coastal Alaska (fig. 1) is divided into two broad areas. These correspond to the general locations of the Tongass National Forest (the southeastern Alaska panhandle) and the Chugach National Forest (the Kenai Peninsula and adjacent south coast, including Afognak Island). The southeast, comprised largely of a group of islands (the Alexander Archipelago), has been described in detail by Harris and others (1974); Federal Power Commission and USDA Forest Service (1947).

The topography of coastal Alaska can be characterized as mountainous and glaciated; though the highest elevations, reaching 7,000 ft (2 000 m) to well over 10,000 ft (3 000 m), are on the eastern and northern borders of the region. Mountains are generally low on the southeastern islands, allowing a vast expanse of forest from tidewater to a timberline near 2,500 to 3,000 ft (750 to 900 m). Stands here are primarily western hemlock (*Tsuga heterophylla*) and Sitka spruce (*Picea sitchensis*), with scattered western redcedar (*Thuja plicata*) and Alaska cedar (*Chamaecyparis nootkatensis*). The timberline decreases to 1,000 to 2,000 ft (300 to 600 m) in the Chugach area. Black spruce (*Picea mariana*), white spruce (*Picea glauca*), and paper birch (*Betula papyrifera*) are important species, and the ones with most fire occurrence, on the Kenai Peninsula (Noste 1969).

Annual precipitation over the region (fig. 2) shows the effects of topography, as well as prevailing storm tracks. Normal amounts near sea level range from about 15 inches (375 mm) on the west side of the Kenai Peninsula (outside the Chugach boundary) to more than 100 inches (2 500 mm) over much of the south coast and panhandle; 200 to 250 inches (5 100 to 6 300 mm) occur at a few locations. Amounts are down to 25 to 30 inches (625 to 750 mm) in the extreme northern interior of the panhandle (outside the Tongass boundary). The warmer months of late spring and summer are generally a relatively dry time of year, though normal monthly rainfall may well exceed 5 inches (125 mm) in the wetter areas, particularly in August; drier areas receive 1 to 2 inches (25 to 50 mm). Average daily maximum temperatures generally reach 60° to 65° F (16° to 18° C) by June or July, approaching 70° F (21° C) at some interior locations.

gure 1.—Map of coastal Alaska (Forest Service, Region 10), showing locations of Chugach and
ongass National Forest (areas highlighted by shading and hatching).

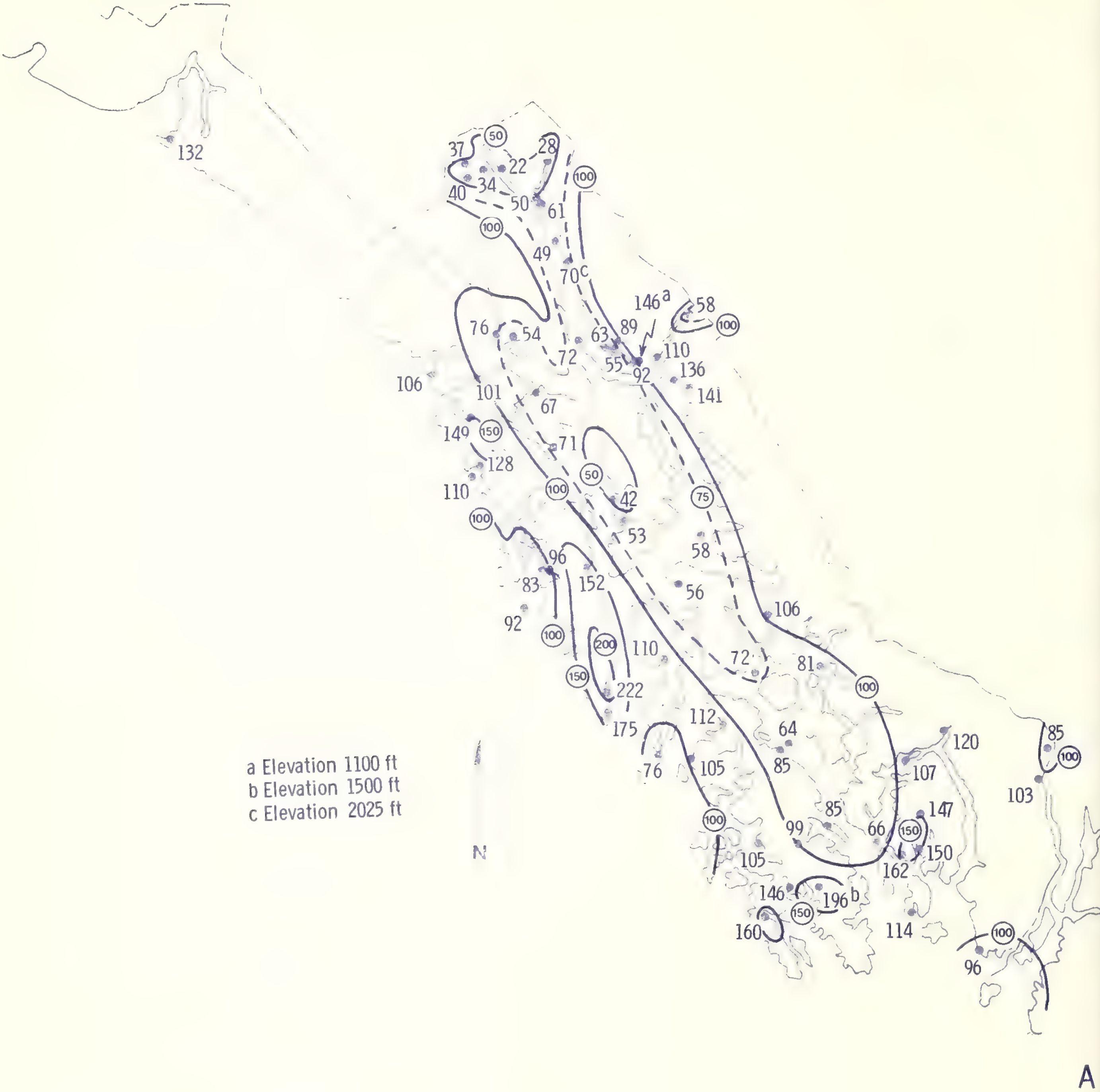

Figure 2.—Average annual precipitation, inches, at stations in coastal Alaska. Mostly based on or adjusted to normal period 1941-70. Solid lines are generalized isohyets drawn at 50-inch intervals; dashed lines are drawn at intermediate 25-inch intervals. Panel A: southeastern panhandle; panel B: Kenai Peninsula and south coast area.


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The main fire season thus covers the period May through August. Overall, in Region 10, these 4 months account for about 80 percent of all wildfire occurrences and 97 percent of the total acreage burned (Noste 1969). In each of these months, there is commonly a period of a week or more with little or no rainfall. On weather maps, these periods are usually identified with persisting upper-air ridges or patterns of airflow from the north or northeast, which also bring higher daytime temperatures and lower relative humidity. Such features cover large areas; both the normally wetter and drier locations are affected. At some time during an average season, there is apt to be a dry spell of between 10 and 20 days over most of the region (fig. 3). Dry-spell duration reached 37 days at Skagway in 1971. A spell of 23 days in the same year at normally moist Ketchikan brought extremely high fire danger and a shutdown of nearby logging operations; a 65-acre (26 ha) fire occurred 2 miles (3 km) to the southeast.

Overall, the annual median area burned in Region 10 during the 40 years, 1940-79, was only 53 acres (21 ha); the median number of fires was 25, most of which did not exceed class size A (¼ acre [0.1 ha]). Only 12 of the total reported fires were attributed to lightning; these, all in the Tongass National Forest, burned a total of 2 acres (1 ha). More than 2,500 acres (1 000 ha) burned within or near the Chugach National Forest in 1950 and again in 1959 and 1969; nearly 1,500 acres (600 ha) burned in the south Tongass area in 1958.

Figure 3.—Lengths of dry spells, arbitrarily defined by absence of 24-hour rainfall >0.04 inch (1.0 mm). Lower left number is average seasonal (May-August) maximum length, in days, based on 10-year sample, 1962-71; lower right number is 10-year extreme length. Top number is average 4-month rainfall, inches, for same period.

METHOD, DATA

In order to delineate fire-climate zones for coastal Alaska, it was first necessary to derive the fire-climate classes comprising these zones. To derive the classes in the context of wildfire potential and, also, to utilize simple climatic data providing greatest areal coverage, the following procedure was employed. Average daily maximum temperature for the May-August season and the average 4-month total rainfall were chosen as the climatic parameters. A multiple regression relationship was calculated between these (the independent variables) and a parameter of fire danger (the dependent variable), using the relatively small number of stations for which the latter item could be obtained. The regression was then applied, as a series of curves, to the temperature and precipitation averages at about 100 additional stations. This gave estimated values of the fire-danger parameter. The fire-climate class limits were set in terms of this parameter.

The climatic averages were compiled primarily from summaries published by the U.S. Department of Commerce, Weather Bureau (1958; 1965), and the Weather Bureau's successor agency, the National Oceanic and Atmospheric Administration (NOAA 1973a,b); data since 1960 were tabulated from Climatological Data monthly summaries for Alaska. Additional averages were obtained from the Federal Power Commission and the USDA Forest Service (1947), Patric and Black (1968), and from printout of a tape at the National Fire Weather Data Library at Fort Collins. For greater comparability among stations, the averages were adjusted, where required or possible, to represent the standard 30-year normal period 1941-70. The adjustment entailed use of the "difference method" for temperature and "ratio method" for rainfall (Oliver 1973). Resulting May-August values have been plotted to nearest whole numbers in figures 4 and 5. (See footnote 2 for station names and monthly details.) No adjustment was made in the temperature averages for effects of differing observation times (Rumbaugh 1934). At airport stations, data are for the actual calendar day; at most other stations, for the 24 hours ending near 4 or 5 p.m. Average maximums in the latter case may be at least 1.0° F (0.6° C) too high.

The parameter of fire danger was based on the former BUI, namely the average May-August number of days with a value of 30 or higher. Significance of this value was mentioned earlier. The data were extracted from the reference in footnote 1 and checked with BUI tabulations by Trigg and Noste (1969). As seen in figure 6, the above numbers of days correlate closely with the May-August average BUI values obtained from the Trigg and Noste (1969) reference. Though the BUI has been replaced operationally, past BUI data as employed here can serve as a useful indicator of fire-climate zones.

Efforts to use a fire-danger parameter from the current National Fire-Danger Rating System (Deeming and others 1977), namely the Energy Release Component (ERC), were abandoned. The ERC values were quite different for different periods of years, contrary to the trends of temperature and rainfall. For example, the 90th percentile ERC at Juneau (Federal Building) during 1968-72 was 26, with average 4-month rainfall 23.0 inches (584 mm); during 1973-79, the corresponding percentile from Juneau airport data was 0, with rainfall (at this drier location) 16.7 inches (423 mm). At Sitka airport, the 1968-72 figures were 21 for the ERC and 16.4 inches (417 mm) for rainfall; the 1973-79 figures were 3 and 15.1 inches (384 mm). The ERC value at Ketchikan changed from 18 to 8, and at Thorne Bay from 25 to 16. Much of the problem appears to lie in assumptions that had to be made by the FIRDAT program (Furman and Helfman 1973). The weather observations available prior to 1973 did not contain some items, such as precipitation duration, important for the ERC computations.

Figure 4.—Average May-August (4-month) rainfall, inches, at stations in coastal Alaska, mostly based on or adjusted to normal period 1941-70. Panel A: southeastern panhandle; panel B: Kenai Peninsula and south coast area.

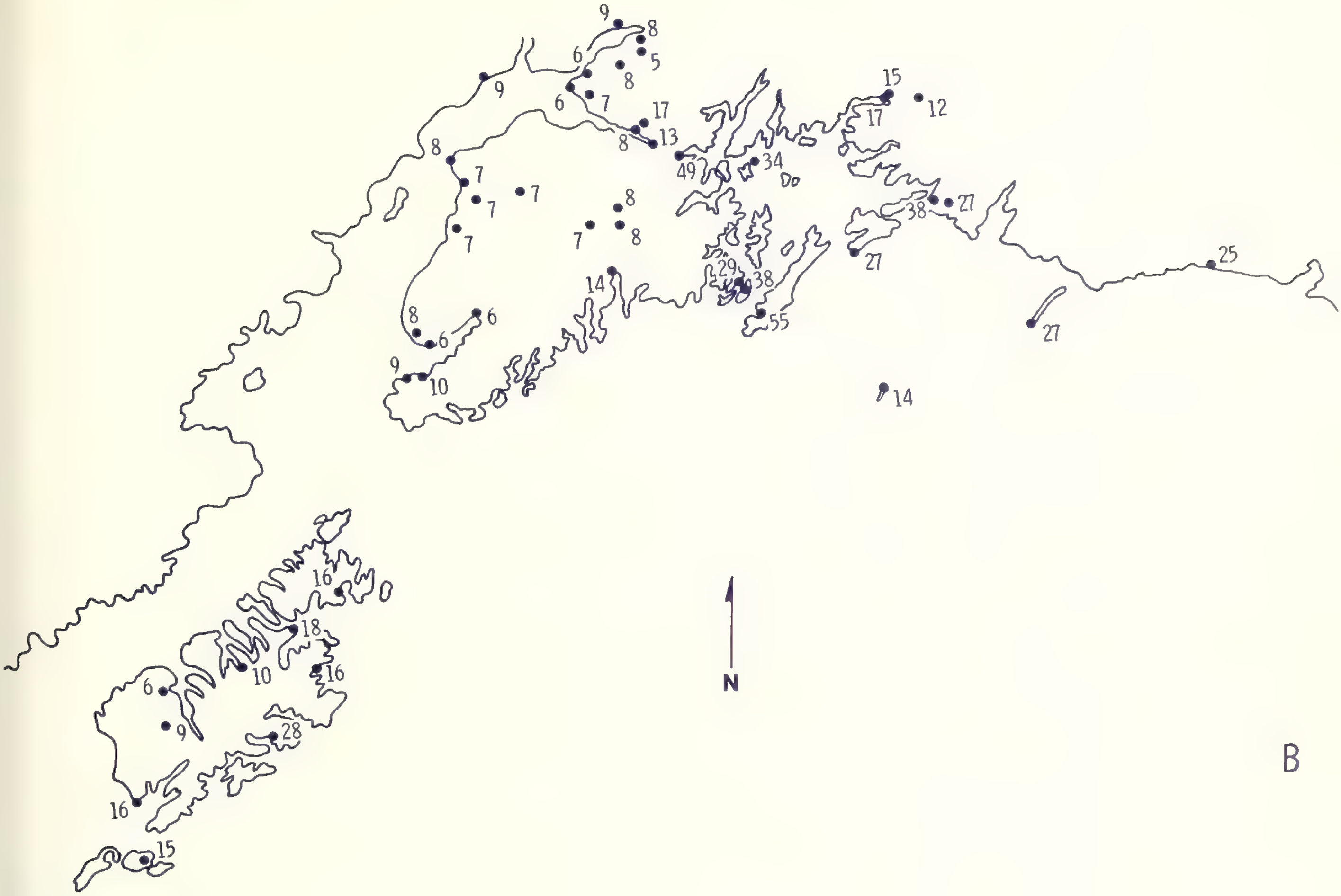
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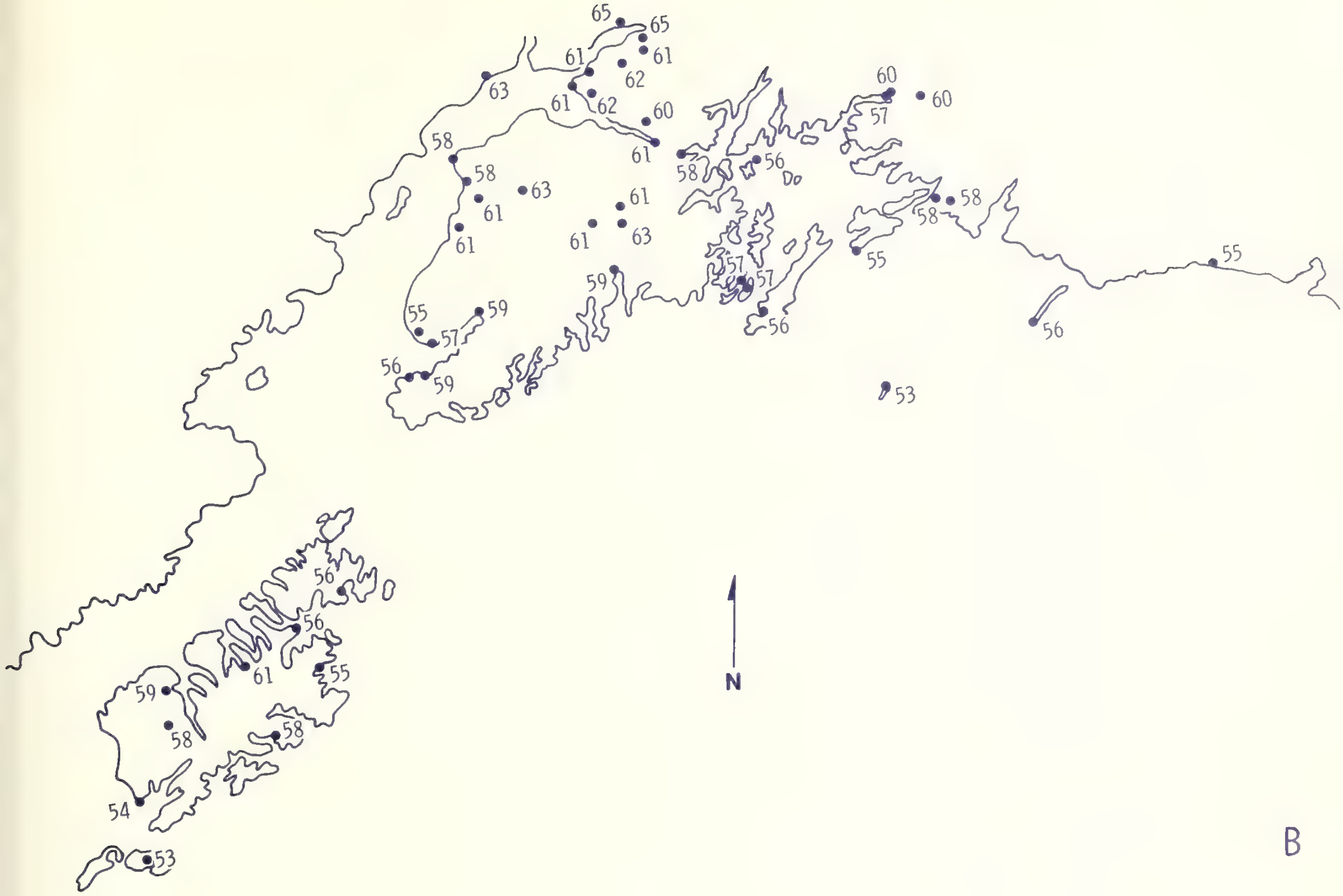
Figure 5.—Average daily maximum temperature (° F) for May-August at stations in coastal Alaska, mostly based on or adjusted to normal period 1941-70. Panels as in figure 4.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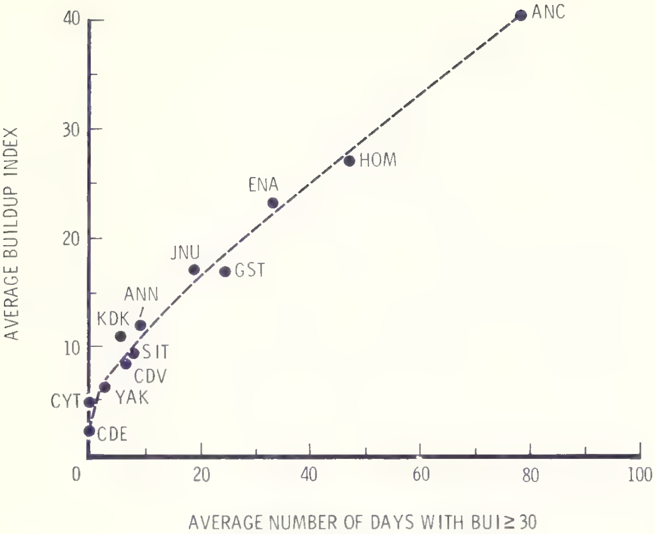

Figure 6.—Relationship between May-August average Buildup Index (BUI) and number of days with value ≥30, coastal Alaska area. Based on 4 p.m. P.s.t. (2 p.m. A.s.t.) observations, 10 years 1956-65. Letters are standard location identifiers (for example, ANC denotes Anchorage; ENA, Kenai; JNU, Juneau; GST, Gustavus; CYT, Yakataga; CDE, Cape Decision).

CALCULATION AND RESULTS

The multiple regression calculation used a computer program from Nie and others (1975). The input data were transformed into logarithms (Freese 1967), as it was evident that the relationship between original variables was curvilinear rather than linear; two of the variables have limiting values of 0.

The assumed equation was:

$\text{LOG } Y = a' + b \text{ LOG } X_1 + c \text{ LOG } X_2$, transformed from a power function

$Y = aX_1^bX_2^c$,

where

Y is the number of days with BUI ≥ 30 (or number of BUI-30 days),

X_1 is the 4-month rainfall, and

X_2 is the average maximum temperature.

In the logarithmic equation, a′ (or LOG a), b, and c are regression constants.

Table 1 lists the input data (before transformation), which are from 18 stations (see fig. 1). Two stations, with zero number of BUI-30 days during the years available, were excluded. Logarithmic transformation would obviously have presented a problem; but, also, the locations, on capes exposed to the open ocean, were considered unrepresentative. Their low BUI values were largely a result of low afternoon temperatures (and associated high relative humidity).

The resulting regression gave a multiple correlation coefficient of 0.95, referring to predicted versus observed values of LOG Y. Even so, some of the differences (or residuals) are large, as seen in figure 7; the values here are transformed back to original units. The regression equation,

$$\text{LOG } Y = -10.596 - 1.520 \text{ LOG } X_1 + 7.638 \text{ LOG } X_2,$$

was used to construct a series of curves (fig. 8) for obtaining estimates of Y and fire-climate class at the large number of additional stations (and for obtaining comparative estimates at the original 18 stations). These curves are drawn for maximum temperature at intervals of 2° F. This element—largely through its influence on relative humidity (Schroeder and Buck 1970)—becomes a more important factor with lower rainfall amounts. The curves do trend toward unrealistically high numbers of BUI-30 days at low rainfall amounts, but (as will be seen) this does not have much practical effect.

Table 1.—Data used for multiple regression, May-August averages

Alaska station	Years	Number of BUI-30 days[1]	Four-month rainfall	Twenty-four-hour maximum temperature
			Inches	*°F*
Anchorage	1956-65	78.9	6.55	61.2
Angoon	1965-68	23.3	7.75	59.0
Annette	1956-65	9.4	27.16	61.5
Cordova	1956-65	6.5	27.76	57.6
Gustavus	1956-65	24.8	14.78	60.1
Hyder	1966-69	55.4	15.0	[2]69.8
Homer	1956-65	47.4	6.29	56.8
Juneau (A.P.)	1956-65	19.2	16.55	60.5
Kenai	1956-65	33.3	7.55	58.1
Kenai Lake	1965-69	86.8	7.30	62.6
Ketchikan	1965-69	3.8	37.23	64.0
Kodiak	1956-65	5.4	15.37	55.4
Petersburg	1965-69	12.8	23.73	61.1
Sitka	1956-69	5.1	23.08	58.5
Skagway	1966-68	83.3	6.49	65.7
Thorne Bay	1965-69	40.2	13.86	[2]65.7
Wrangell	1965-69	6.8	19.09	60.9
Yakutat	1956-65	2.9	39.52	57.0

[1]Number of days with former Buildup Index (BUI) ≥ 30.
[2]Estimated from average dry bulb at 4 p. m. P.s.t.

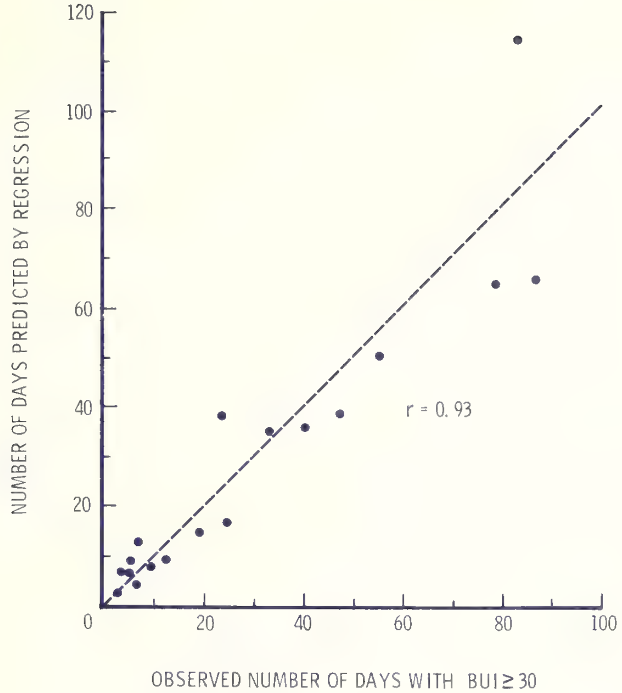

Figure 7.—Observed number of days with Buildup Index (BUI) ≥ 30 versus number predicted by multiple regression. Dashed line represents 1:1 ratio.

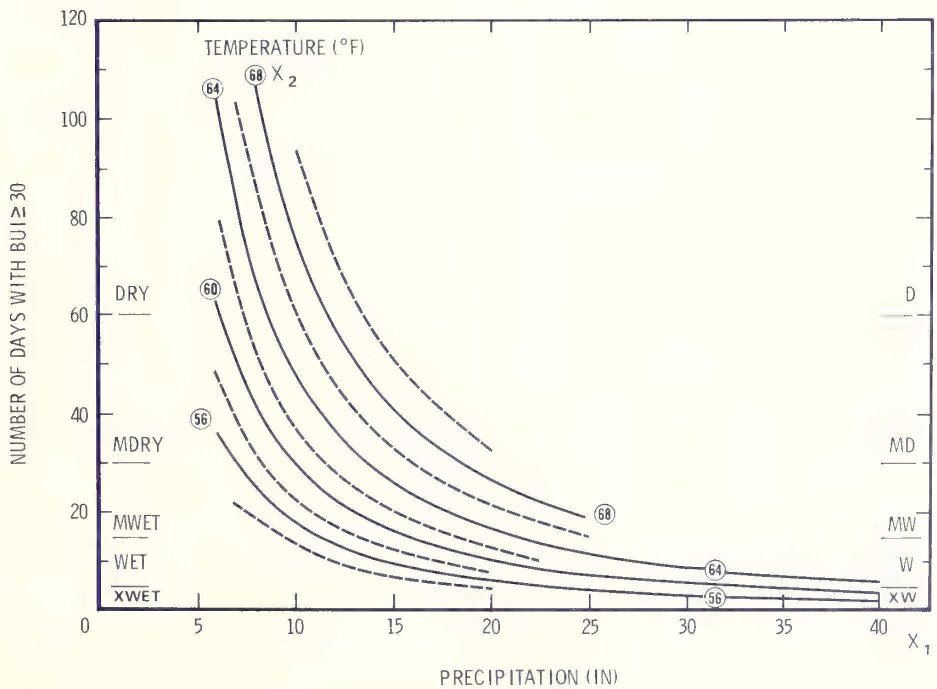

Figure 8.—Curves based on multiple regression equation, for estimating average May-August number of days with Buildup Indexs (BUI) ≥30, given the average 4-month rainfall (X_1) and average daily maximum temperature (X_2). Curves are labeled in degrees Fahrenheit. Horizontal lines at edges denote limits for defined fire-climate classes.

The Fire-Climate Classes and Zones

The derivation of fire-climate classes considered the total number of days, 123, in the May-August fire season. The driest class was arbitrarily defined as having BUI-30 occurrence on one-half or more of all days; the lower limit was rounded to 60 days. For other classes, limits were successively halved to 30 and 15 days. A final, wettest class had an upper limit set at 5 days. This nearly geometric progression concentrates the fire-climate distinction within the range of BUI-30 days covering most of coastal Alaska. The excessive upward trend of the curves already noted in figure 8 occurs mostly outside the range of observed data. Where unrealistically high numbers of BUI-30 days are obtained, the fire-climate class may still be correct, due to the large leeway within the driest class.

The fire-climate classes, included in figure 8, have been named (and abbreviated) as follows: dry (D), moderately dry (MD), moderately wet (MW), wet (W), and extremely wet (XW). The driest class is dry in a relative sense; no stronger designation could realistically be applied anywhere in coastal Alaska.

Based on figure 8 and the temperature and rainfall averages shown in figures 4 and 5, the fire-climate zones have been drawn in figure 9. The boundary lines are, necessarily, generalized. They are drawn to closely fit the BUI results, for stations near sea level, but follow the larger scale topographic features and their inferred influences. The zones refer mainly to the lower elevations of the forest belt.

Summertime upper-air data, available from Anchorage, Annette, and Yakutat (and examined in footnote 2), indicate that the dominant Pacific airmasses usually extend throughout the forest elevations. Nighttime surface temperature inversions from radiational cooling do occur, but "marine" inversions (above which the air is warmer day and night and also much drier) are infrequent. This evidence, together with an indicated increase in precipitation with elevation (Federal Power Commission and USDA Forest Service 1947; Walkotten and Patric 1967; Schmiege and others 1974), suggests that in general the fire danger buildup decreases with elevation.

The features seen in figure 9 include: (1) a moderately wet zone, up to about 50 miles (80 km) wide, extending through nearly the entire length of the southeastern Alaska panhandle. This zone is situated between wet or extremely wet zones toward the west and east; (2) imbedded moderately dry pockets on at least two of the islands (Admiralty and Prince of Wales); (3) dry or moderately dry areas along the inlets and river valleys in the extreme northern panhandle and extreme east (along the Portland Canal and Taku River); (4) a dry zone covering most of the Kenai Peninsula west of the Kenai Mountain Divide; (5) a strong gradient across this divide to wet and extremely wet zones covering all of the south coast area; and (6) a wet zone over eastern Afognak Island (north of largely unforested Kodiak Island), with a moderately wet zone inferred over inland and sheltered portions to the west.

The pattern in figure 9 roughly follows that of annual precipitation (see fig. 2). In this generalized portrayal of zones, there is no attempt to show an apparent XW zone in the Coast Mountains (for example, east of Juneau and Petersburg), which would not include much forested area.

SUMMARY

This report has presented a method that was used to delineate fire-climate zones in the coastal Alaska area. Climatic data input consisted of simple averages—those of 4-month rainfall and daily maximum temperature during the May through August fire season. Fire-climate classes comprising the zones were derived by a multiple regression using the climatic averages and a fire-danger parameter at 18 stations. This parameter, from a former National Fire-Danger Rating System, was the average number of days with a BUI of 30 or greater (number of BUI-30 days); the value of 30 was previously found to be a threshold with respect to fire suppression in logging slash in coastal Alaska. The regression had high statistical significance; with all data converted to logarithms, the multiple correlation coefficient was 0.95. Curves based on the regression equation were applied to the climatic averages at more than 100 stations.

Five fire-climate classes were defined with limits generally based on a doubling of the number of BUI-30 days; divisions are at 60, 30, 15, and 5 days. The classes are termed dry (D), moderately dry (MD), moderately wet (MW), wet (W), and extremely wet (XW). The delineated fire-climate zones generally represent the lower forested elevations, though the boundaries follow the large-scale topographic features and their inferred influences. The fire-danger buildup in this region appears to usually decrease with elevation (away from open coasts). This is implied by temperature and humidity data from regular upper-air soundings, together with an indicated increase in precipitation with elevation.

Dry zones were defined over most of the Kenai Peninsula west of its major divide and in the extreme northern interior of the panhandle. A few moderately dry areas are found further south in the panhandle—between W or XW zones toward the Pacific Ocean and the eastern mountains—and along river valleys of the extreme east.

The method described here may employ a fire-danger parameter from the current national system. In the present case, lacking much of the required data, such a parameter could not be reliably calculated. The author does not believe that there is as yet one best method or approach; much may depend on the geographic (or broad climatic) region, as well as the type, amount, and quality of data available. In any method, however, defined fire-climate zones should ideally relate to an actual fire-danger index or parameter.

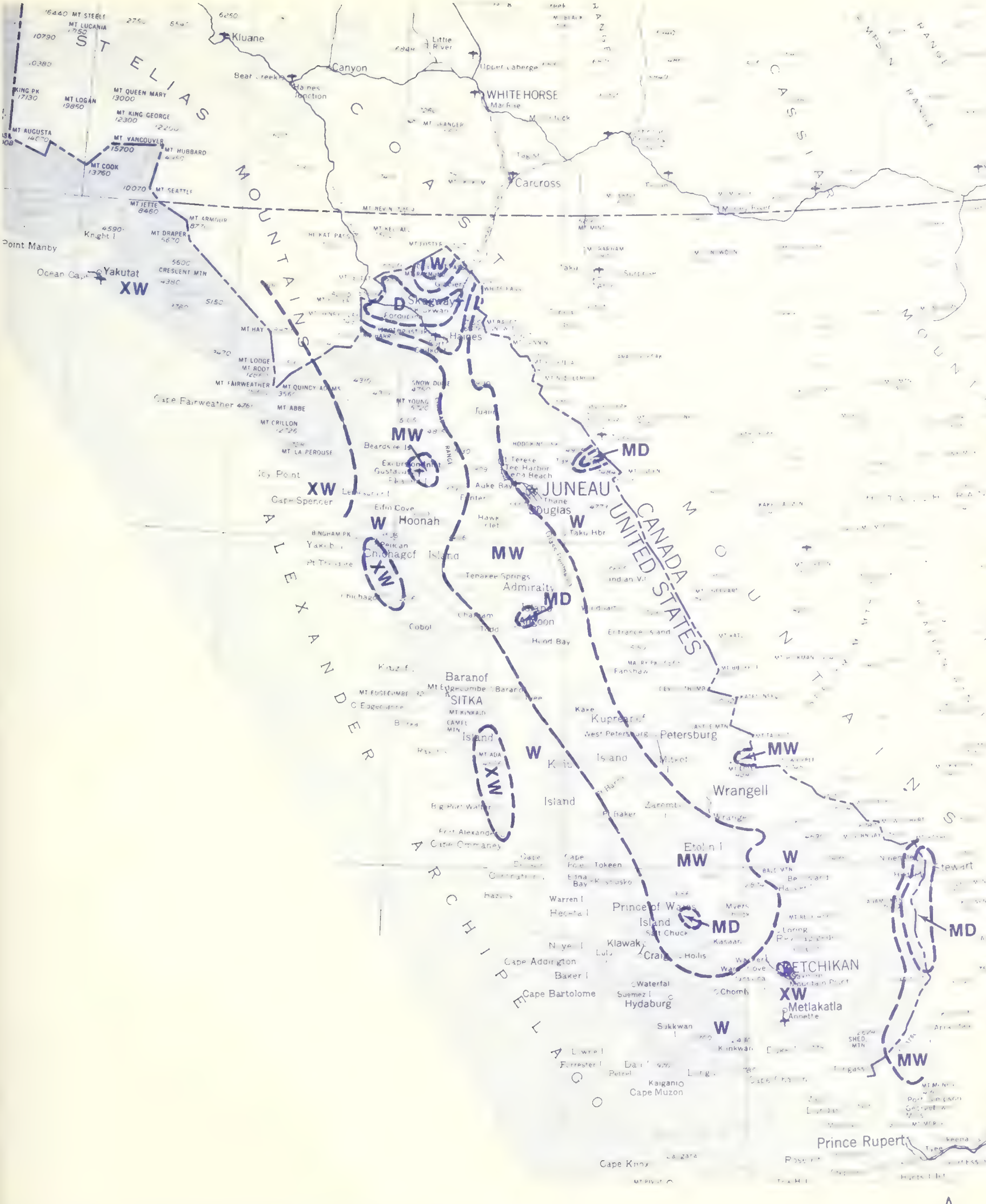

Figure 9.—Fire-climate zones delineated (by dashed lines) for coastal Alaska. Panel A: southeastern Alaska; panel B: Kenai Peninsula and south coast area. D denotes dry; MD, moderately dry; MW, moderately wet; W, wet; XW, extremely wet.

Figure 9.— (con.)

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Delineates fire-climate zones for coastal Alaska (Forest Service, Region 10). The zones are based on five fire-climate classes derived through multiple regression using simple climatic averages—May-August rainfall and daily maximum temperature—and a parameter of fire danger. The regression, based on data from 18 stations, was applied to the climatic averages from about 100 additional stations.

KEYWORDS: climate, fire-climate zones, fire-management planning

The Intermountain Station, headquartered in Ogden, Utah, is one of eight regional experiment stations charged with providing scientific knowledge to help resource managers meet human needs and protect forest and range ecosystems.

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General Technical
Report INT-129

August 1982

Handbook for Inventorying Surface Fuels and Biomass in the Interior West

James K. Brown, Rick D. Oberheu,
and Cameron M. Johnston

THE AUTHORS

JAMES K. BROWN received his bachelor's degree from the University of Minnesota in 1960, his master's from Yale University in 1961, and his Ph.D. from the University of Michigan in 1968, all in forestry. From 1961 to 1965, he did research on field measurement of fuel properties and fire-danger rating systems while with the Lake States Forest Experiment Station. In 1965, he transferred to the Northern Forest Fire Laboratory, Missoula, Mont., where he conducted research on the physical properties, inventory, and prediction of fuels. He currently is leader of a fire effects and use project in Missoula.

RICK D. OBERHEU received his bachelor's degree in forestry from the University of Montana in 1973. In 1974, he joined the Northern Forest Fire Laboratory, where he worked extensively with fuel and vegetation inventory on a fire effects and use project. He currently is a fuels management specialist on the Wallowa-Whitman National Forest.

CAMERON M. JOHNSTON attended the University of Montana from 1965 to 1969. He worked as an engineering data processor for the USDA Forest Service Northern Region from 1969 to 1972. In 1972, he became the computer programmer for the fuel science research work unit at the Northern Forest Fire Laboratory. In 1978, he became the computer specialist for the Division of Aviation and Fire Management for the Northern Region. He currently is a programer analyst with the Fire Effects and Use R and D Program at the Northern Forest Fire Laboratory.

RESEARCH SUMMARY

Comprehensive procedures for inventorying weight per unit area of living and dead surface vegetation are presented to facilitate estimation of biomass and appraisal of fuels. The authors show how to conduct fieldwork and estimate weight per unit area of downed woody material, forest floor litter and duff, herbaceous vegetation, shrubs, and small conifers. Weights by species are determined for shrubs and small conifers. Coverage of shrubs and herbaceous vegetation are estimated. The several sampling methods involve the counting and measuring diameters of downed woody pieces that intersect vertical sampling planes, comparing quantities of litter and herbaceous vegetation against standard plots that are clipped and weighed, tallying shrub stems by basal diameter classes, tallying conifers by height classes, and measuring duff depth. The procedures apply most accurately in the Interior West; however, techniques for herbaceous vegetation, litter, and downed woody material apply anywhere. A computer program and card punching instructions are included for processing inventory data.

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INTRODUCTION

This publication describes procedures for inventorying weight of forest floor duff, forest floor litter, herbaceous vegetation, shrubs, small conifers, and downed woody material (fig. 1). The procedures furnish estimates for live and dead vegetation by diameter classes. The inventory methods have application to several facets of forest and range management and to research investigations.

The procedures were initially developed to provide estimates of fuel loading (weight per unit area) as part of an effort to appraise fire behavior potential for planning fire strategies in wilderness areas (Habeck and Mutch 1973; Aldrich and Mutch 1972). Although the methodology emphasizes forest fuels, estimates of aboveground biomass of herbaceous vegetation, shrubs, and small conifers may be useful for purposes other than fuel

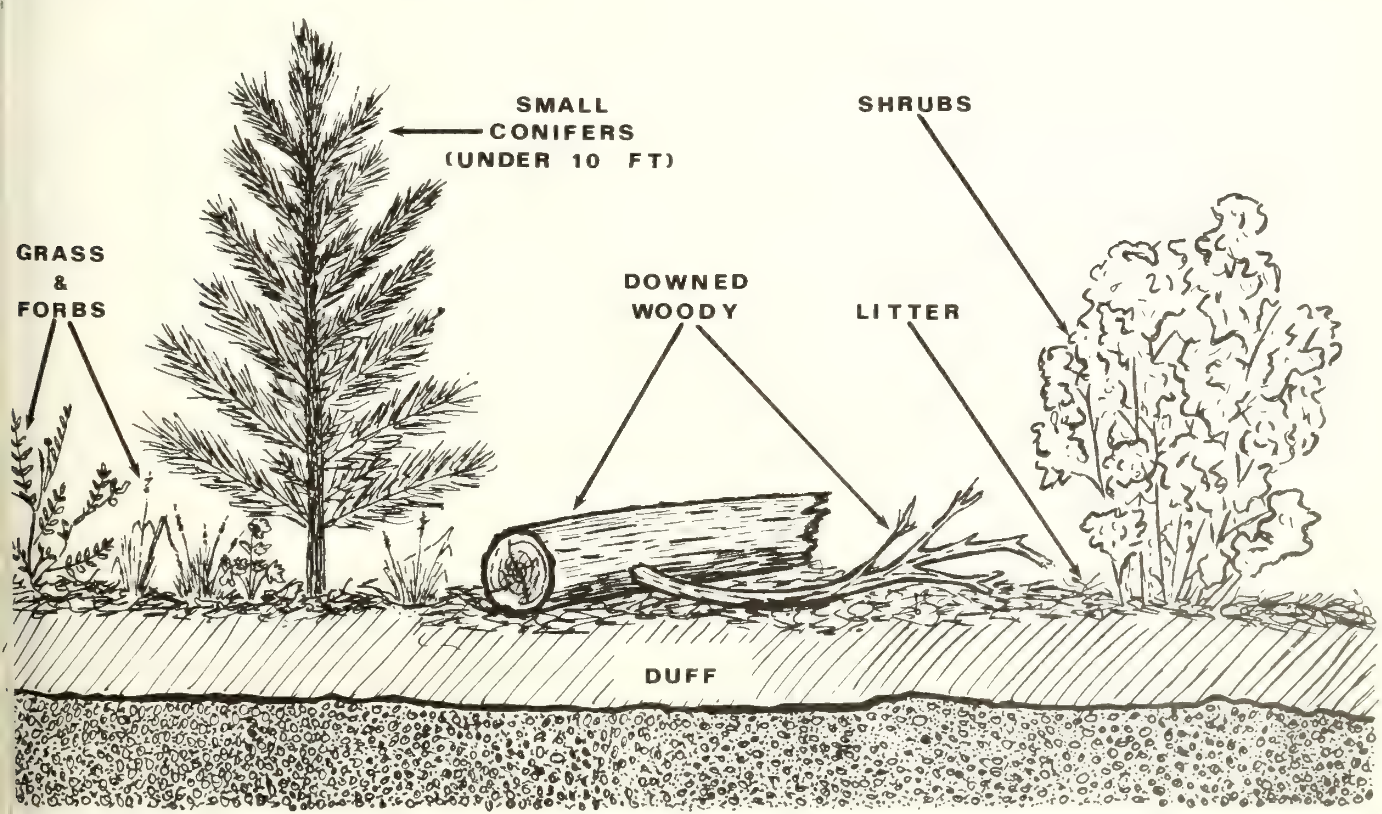

Figure 1.—Vegetative components included in procedures for estimating biomass and fuel loading.

appraisal. The procedures were used by numerous field crews for several years. This experience aided considerably in developing the step-by-step procedures reported here.

The inventory procedures are useful for determining biomass of any vegetation up to about 10 ft (3 m) in height. The entire set of procedures or a part of them can be applied to estimate all or any one of the vegetative components.

The procedures apply most accurately in the Interior West. The techniques for estimating biomass of herbaceous vegetation, litter, and downed woody material, however, apply anywhere. The shrub techniques apply most accurately to shrubs in the Northern Rocky Mountains. Considering sampling efficiency as attainment of desired precision by the most practical means, the most efficient methods of sampling vegetation vary by plant species and purpose. Different techniques are required to most efficiently sample all vegetation. Thus, the single set of procedures assembled here may not be the most efficient for some situations. Nevertheless, the procedures are appropriate for sampling each category of vegetation and can be widely applied with a minimum of training and experience. Further discussion on applicability of techniques is in appendix I.

The inventory procedures specify sampling of branch and stemwood under 3 inches in diameter by diameter classes of 0 to 0.25 inches (0 to 0.6 cm), 0.26 to 1.0 inches (0.6 to 2.5 cm), and 1.0 to 3.0 inches (2.5 to 7.6 cm). The size classes correspond in increasing size to 1-, 10-, and 100-hour average moisture timelag classes for many woody materials (Fosberg 1970). The size classes are used as moisture timelag standards in the U.S. National Fire-Danger Rating System (Deeming and others 1977). A moisture timelag is the amount of time for a substance to lose or gain approximately two-thirds of the moisture above or below its equilibrium moisture content. Appraisal of forest fuels is greatly facilitated when data on biomass are assimilated by these size classes.

Fuel depth was originally included in the procedures but was removed because interpretation of fuel depth was complex and required trained people to evaluate the reasonableness of depth observations. Although Albini (1975) developed an algorithm that was largely successful in processing fuel depth data for input to Rothermel's (1972) fire spread model, spurious depth measurements coupled with the fact that fire behavior predictions were highly sensitive to depth, continued to cause erratic predictions. In predicting fire behavior using Rothermel's model, depth together with loading is required to determine fuel bulk density. Recent research (Brown 1981) indicates that characterization of bulk density for understory vegetation and fuel groups may eliminate the need for measurement of fuel depth in inventorying fuel for practical applications.

To assure reasonable fire behavior predictions, inventoried fuel loadings should be interpreted by fire behavior modeling specialists for proper input to Rothermel's model. Estimates of certain fuel components such as downed woody material and duff can be used without interpretation in operating Albini's (1976) burnout model. This model is incorporated in a computer program called HAZARD, which appraises slash fuels (Puckett and othe 1979). As the technology in fire behavior modeling grows other direct applications of fuel inventory may arise.

CHOICE OF TECHNIQUES

An efficient inventory of all fuel and understory vegetation requires several techniques because of the varied physical attributes of vegetation. Forest vegetatio is comprised of living and dead plants, both standing an downed. Plants range in size from small grasses and forbs to large shrubs and trees. Pieces of vegetation con sidered as fuel particles range in size from small leaves, needles, and twigs to large branches and tree boles. Vegetation and fuels having similar physical characteristics, which can be appropriately sampled using the same technique, can be grouped as follows:

1. Standing trees
2. Shrubs
3. Herbaceous vegetation (grasses and forbs)
4. Forest floor litter (01 horizon)
5. Forest floor duff (02 horizon)
6. Downed woody material.

The inventory procedures assembled here are made u of different techniques for each category of vegetation. Before presenting the procedures, methods of sampling and reasons why certain techniques were chosen are di cussed for each category of vegetation.

Standing Trees

A method for estimating biomass of conifers less tha 10 ft (3 m) in height was included in the procedures presented here because small trees can contribute significantly to propagation of both surface and crown fires. T method requires measurement of number of trees per acre by species and height. Biomass of foliage and branchwood by size class is calculated from weight and height relationships developed by Brown (1978).

Biomass of trees over 2 inches (5 cm) d.b.h. can be estimated from biomass tables or from tree volume estimates converted to weight using wood densities (USDA 1974). determine volumes from tree volume tables, estimates the number of trees per acre or basal area per acre by d.b.h. and species required to access the tables can be determined from commonly used plot and plotless sam ling methods. Procedures for inventorying trees greater than 10 ft (3 m) in height are not included here because they are commonly understood and used in forestry. If desired, they can be readily applied along with the procedures for surface vegetation.

Shrubs

Shrub biomass can be estimated nondestructively by one of two basic methods. One approach relates biomass to stem diameters as described by Telfer (1969) for shrubs in eastern Canada, and Brown (1976) for shrubs in the Northern Rocky Mountains. High correlations between stem diameters and weights of various shrub parts hav been reported (Lyon 1970; Buckman 1966; Whittaker 19). This approach requires a tally of number of stems by stem diameter on plots of known size. Another method relies on the relationships between biomass, canopy ar

and canopy volume as described for semidesert shrubs in New Mexico (Ludwig and others 1975), sagebrush *Artemisia tridentata*) (Rittenhouse and Sneva 1977), and ow shrubs in California (Bently and others 1970). This method requires measurements of crown diameters and shrub height.

The method involving measurement of stem diameters as the advantage of applying easily to tall shrubs compared to the method of measuring crown dimensions. Measurement of stem diameters probably permits the most accurate estimation of biomass because stem diameters should relate more directly to biomass than does space occupied by shrubs. A disadvantage of measuring stem diameters is that fieldwork can involve considerable time, especially for small shrubs comprised of many stems such as grouse whortleberry (*Vaccinium scoparium*). The fieldwork can be minimized by recording diameters by size classes. The method requiring measurement of crown dimensions is rapid and well suited to small- and medium-size shrubs. The method involving measurement of stem diameters was incorporated in hese procedures because it applies to shrubs of all sizes, and relationships for estimating biomass of leaves and temwood by diameter class were available for 25 species Brown 1976).

Herbaceous Vegetation

An extensive body of literature exists on estimating weight and production of range vegetation. Techniques or estimating weight basically fall into three categories:) clipping and weighing, (2) estimation, and (3) a ombination of weighing and estimation.

To aid in extensive surveys, a quick, easy-to-use method is needed for estimating weight. Studies in asture grasses (Pasto and others 1957) and annual range pecies (Reppert and others 1962) gave reasonably high orrelations between weight per unit area, and ground over and height. Similar investigation of grasses, forbs, nd small woody plants in forest areas showed that as ore plant sizes and shapes are included in plots, poorer ccuracy can be expected (Brown and Marsden 1976). nless relationships of suitable accuracy are known for pecific sites, some clipping and weighing is desirable for stimating herbaceous vegetation.

The weight-estimate method has been widely used and sted in the southern and western United States in a riety of vegetation including large and small grasses d understory vegetation. It requires an estimate of tual weights and can be effectively used with double mpling on clipped and weighed plots. Trained observers n estimate within 10 percent of actual weights (Hughes 959). When used with double sampling, variance of estiates can be reduced (Francis and others 1979). This ethod, coupled with double sampling, has proved very seful in estimating forest floor litter and herbaceous els for research purposes.

Another similar technique, the relative-weight estimate ethod (Hutchins and Schmautz 1969) has been useful in timating fuels. This method is based on the assumption at it is easier to compare weights than estimate ights. It involves identifying a base plot having the ost weight from a set of four or five plots. The weight on the other plots is estimated as a fraction of the base plot. The base plot is then clipped and weighted and weights on other plots calculated as a fraction of the base plot.

The relative weight-estimate method was incorporated in these procedues because it is easy to use, requires a minimum of training, and is based on some clipping and weighing. The advantages and disadvantages of this method include:

Advantages

1. Requires little training or experience to learn the method; remembering weight images is minimal.
2. Checking weight estimates against actual weights is unnecessary.
3. Estimates are not affected by changes in light and moisture content as can happen with the weight-estimate technique.
4. Quantities of vegetation can be rated on a relative basis more easily than they can be actually estimated.

Disadvantages

1. The set of plots must all be readily visible to the observer to permit accurate comparisons.
2. Clipping and bagging on one out of every four or five plots is necessary.
3. Accuracy of the method has had little study.
4. Probably not as accurate as weight-estimate method used by trained and experienced observers.

Litter and Duff

Sampling the forest floor litter separately from the duff is desirable because the litter is usually much less dense than the duff and frequently burns independently of the duff. The most accurate method of estimating forest floor weights is by collecting and weighing samples. This necessitates a cumbersome field procedure involving transport of soil containers and eventual ovendrying. Attempts to correlate stand characteristics and forest floor weights and depths have not always been successful. For example, forest floor weights in red pine plantations (Dieterich 1963) and ponderosa pine stands (Ffolliott and others 1968) were highly correlated with tree basal area. On the other hand, relationships between forest floor weights and basal area, site index, and stand age were insignificant in natural stands of red pine and jack pine (Brown 1966), and poorly correlated in eastern white pine (Mader and Lull 1968). In an extensive study of southwestern ponderosa pine and mixed conifers, Sackett (1979) found a lack of reliable relationships for predicting forest floor quantities from basal area or duff depth. Factors such as fire history, decay rates, and storms can strongly influence forest floor quantities. Thus, high correlations between forest floor quantities and basal area, site index, and stand age appear to have a limited basis—low correlations should not be surprising. The relationship between depth and weight of duff can be used to estimate weight recognizing that accuracy can be low. Measurement of duff depth was adopted for these procedures because:

1. Collecting and weighting duff would be impractical for large inventories.
2. The literature on duff bulk density seemed substantial enough to use in estimating weight from depth.

3. Depth is easily measured and can be a useful measurement itself for planning and evaluating prescribed fires conducted for fuel reduction and site preparation.

The bulk densities in table 1 served as a basis for establishing the following bulk densities that are used in the computer program to calculate duff loadings from duff depth:

Cover type	Bulk density
	Lb/ft³
1. Ponderosa pine	5
2. Lodgepole pine	8
Douglas-fir	
Shrubfields	
Grand fir	
3. Others	10

Because the bulk densities used to calculate duff weights are approximations, the weights are approximations and must be interpreted accordingly. If desired, bulk densities other than those above can be used to calculate duff loadings as described in the section on calculations.

Litter depth was not adopted as a basis for estimating litter weight because the literature on bulk density of litter was scant. More important, perhaps, is that considerable judgment is required to identify the top of litter. This problem is serious because the litter layer is often very thin and large errors in depth measurement could result. The relative weight-estimate technique was chosen for litter because it applies readily to litter and was also being used for herbaceous vegetation.

Downed Woody Material

Downed woody material is the dead twigs, branches, stems, and boles of trees and shrubs that have fallen and lie on or above the ground. Loadings of downed woody material vary considerably among stands due primarily to site productivity and stand history (Brown and See 1981).

Collecting and weighing downed woody material is impractical in most forest stands. The planar intersect technique (Brown 1974b; Brown and Roussopoulos 1974) adopted here is nondestructive and avoids the time-consuming and costly task of collecting and weighing large quantities of downed woody material. It has the same theoretical basis as the line intersect technique (Van Wagner 1968). The planar intersect technique involves counting intersections of woody pieces with vertical sampling planes that resemble guillotines dropped through the downed debris. Volume is estimated; then weight is calculated from volume by applying estimates of specific gravity of woody material.

PROCEDURES

The procedures in this section are an assembly of sampling techniques that provide estimates of the following variables:

1. Biomass and fuel loading on an ovendry basis of:
   a. Downed woody material
   b. Forest floor litter and duff
   c. Herbaceous vegetation
   d. Shrubs
   e. Conifers less than 10 ft (2 m) in height.
2. Depth of duff and height of shrubs and small trees
3. Percentage cover of herbaceous vegetation and shrubs.
4. Percentage of dead in herbaceous vegetation and shrubs.
5. Percentage cover of forest floor litter.
6. Number of small trees per acre by species.
7. Stand age.

In addition, provision is made for recording and summarizing slope, elevation, aspect, cover type, and habita type.

The field procedures involve counting shrub and smal tree stems and intersected pieces of downed woody

Table 1.—Bulk densities of forest floor duff summarized from literature

Forest type	Location	Forest floor layer	Bulk density: Mean	Bulk density: Standard deviation	Source
			Lb/ft³		
Ponderosa pine	Mont.	F, H	4.8	2.10	Brown (1970)
	Ariz.	F	1.8	0.15	Ffolliott and others (196
		H	7.4	.44	
Ponderosa pine	Wash.	Basalt (F,H)	6.9		Wooldridge (1968)
		other soil (F,H)	4.9		
Mixed conifers	Wash.	Basalt (F,H)	6.9		Wooldridge (1968)
		other soil (F,H)	6.0		
Eastern white pine	Mass.	F	4.5		Mader and Lull (1968)
		H	9.0		
Lodgepole pine	Wyo.	F. H	8.7	1.9	Brown (1974a)
Fir – hemlock	Wash.	Mull (F,H)	9.1		Williams and Dyrness (1
Fir – hemlock	Wash.	Mull (F,H)	11.2		Mader (1953)
White spruce, balsam, poplar	Ontario	Mull (F,H)	10.0		Mader (1953)
White pine	Wisc.	Mull (F,H)	8.7		Mader (1953)
White pine/hemlock	N.Y.	Greasy Mor (F,H)	11.9		Mader (1953)
Red pine	Minn.	F,H	4.3		Brown (1966)
Jack pine	Mich.	F,H	6.1		Brown (1966)

naterial; measuring diameters, depth, and height of vege-ation; ocularly estimating percentage of cover and ercentage of dead vegetation; and extracting increment ores for determining tree age. All the procedures may be ollowed to furnish estimates of all vegetation, or a ubset of the procedures may be used to furnish an esti-nate of any single variable such as duff depth or shrub iomass. For an average amount of vegetation, about 15 ninutes per sample point are required to complete neasurements. Counting shrubs and clipping herbaceous egetation and litter require the most time.

Deciding when to sample.—The time of year when egetation, especially grasses and forbs, is sampled has large influence on results. Grasses and forbs may not e fully developed during late spring or early summer. ampling at that time will result in low estimates. During ate summer, some annuals may have cured and deterior-ted to such an extent that their biomass cannot be ccurately estimated. The time of year when sampling is one must agree with the purpose of inventory. For ppraising fuels, sampling during the normal fire season, uch as late July and August in the western United tates, is recommended.

lumber of Sample Points

For any area where estimates are desired, at least 15 to) sample points should be located. This sampling inten-ty will often yield estimates having standard errors ithin 20 percent of the mean estimates (appendix II). reas larger than approximately 50 acres containing a gh diveraity in amount and distribution of fuel and egetation, should be sampled with more than 20 points achieve standard errors within 20 percent of mean stimates.

Changing the size of plots also influences the desired imber of sample points. For sampling downed woody aterial, these procedures accommodate a variable ngth sampling plane. Choose sampling plane lengths om the following tabulation:

Downed material	Diameter of debris 0-1 inch	1-3 inches	>3 inches
	----- *Sampling plane (ft)* -----		
Nonslash (naturally fallen material)	6	10-12	35-50
Discontinuous light slash	6	10-12	35-50
Continuous heavy slash	3	6	15-25

If material larger than 3 inches (7.6 cm) in diameter is anty or unevenly distributed, the longer sampling planes the tabulation should be used.

For fuel and vegetation other than downed woody aterial, plot sizes could be changed. If the computer ogram listed in appendix III is used to calculate load-is, however, it would have to be modified or its output rrected to adjust for different plot sizes. Variable mpling plane lengths are accounted for in the program.

The amount and distribution of vegetation, especially wned woody material, varies greatly among and within nds. Thus, these sampling recommendations should be nsidered approximate because a greater or fewer number of sample points may be required to furnish adequate precision for any given area. Sampling inten-sities are discussed further in appendix II.

Fieldwork

Locating Sample Points

After determining sampling area, such as a stand, delineate or describe its boundaries. Definition of the area and its boundaries should satisfy a sampling design based on a clear objective for the sampling. Sample points may be systematically or randomly located; how-ever, systematic placement is usually the most practical. Two methods are:

1. Locate plots at a fixed interval along transects that lace regularly across a sample area (uniform sampling grid). For example, on a sample area, mark off parallel transects that are 5 to 10 chains (100 to 200 m) apart. Then, along the transects, locate plots at 1- to 5-chain (20- to 100-m) intervals.
2. Locate plots at a fixed interval along a transect that runs diagonally through the sample area. To minimize bias, have the transect cross areas where changes in fuels or biomass are suspected. Before entering the sample area, determine a transect azimuth and distance between plots. Distance between plots can be paced by foot or sampling rod. If variations in biomass across an area are obvious and significant, it may be desirable to divide the area into recognizable strata and sample each stratum separately.

Hints for conducting fieldwork are listed in appendix IV.

Plot Layout

The plot layout at a sample point consists of a randomly positioned line transect for downed woody material and duff, a 1/300-acre plot for trees, two ¼-milacre plots for shrubs, and four 0.98 by 1.97-ft (30 by 60-cm) plots for herbaceous material and litter (fig. 2).

Downed woody material, litter, herbaceous vegetation, shrubs, and small trees are measured on plots laid out parallel to the slope. Thus, calculations of loading on a horizontal acre basis require slope correction. Duff depth is measured vertically so that slope adjustment is un-necessary for calculating loading.

Step 1: Mark the sampling point with a chaining pin (No. 9 wire or similar item). Avoid disturbing material around the point so that measurements can be accurately made.

Step 2: Randomly determine direction of the sampling plane in one of two ways:

(1) Toss a die to indicate one of six 30° angles between 0° and 150°. The 0° heading is the direction of travel. Turn a fixed direction, such as clockwise, to position the sampling plane.

(2) Orient the sampling plane in the direction indicated by the second hand of a watch at a given instant. To avoid bias in placement of the sampling plane, do not look at the fuel or ground while turning the interval.

Step 3: Denote position of sampling plane by placing a 6.8-ft inventory rod (diameter of 1/300-acre plot) out from the chaining pin parallel to the ground in the direction determined in step 2 (fig. 2). A

50-foot tape is used along this same line to measure large pieces. The tape and rod fix the position of vertical sampling planes.

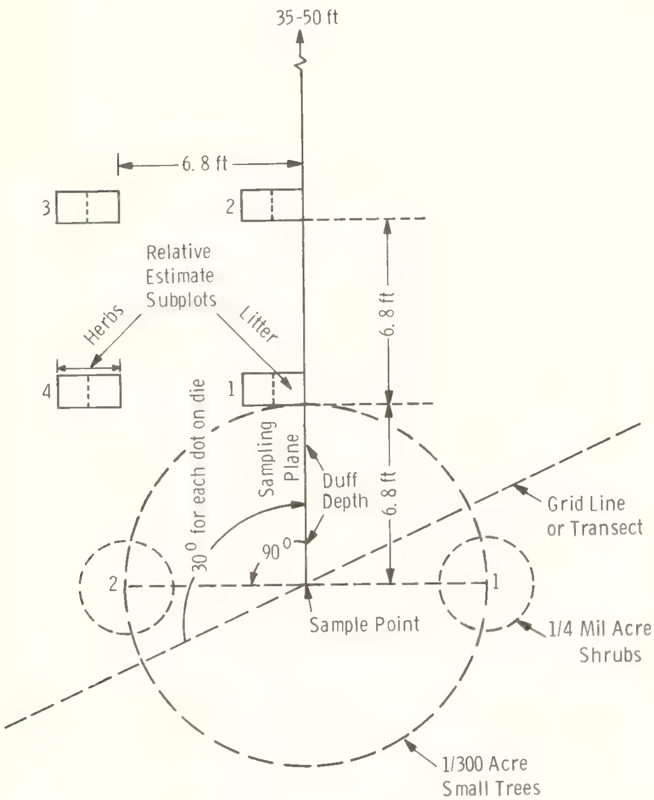

Figure 2.—Plot layout at a sample point.

Step 4: Next, locate four relative estimate subplots and two ¼-milacre shrub plots on the ground as shown in figure 2. Mark the two shrub plots wit chaining pins or similar devices. They are locat 90° to the sampling plane. Place the relative estimate frames parallel to the slope, and main tain this position when collecting samples (fig. Similarly, count shrub stems from plots delineated parallel to the slope.

Vegetation to be sampled by each technique is summarized in table 2. Some vegetation could be sampl by more than one technique. To avoid double sampling any component, definitions of vegetation to be sampled by each technique must be consistently and closely followed.

Figure 3.—Positioning sample frames for the relative estimate technique on the surface of the forest floor.

Table 2.—Vegetation to be sampled by different biomass techniques

Vegetation category	Technique	Sampled vegetation
Downed woody material	Planar Intersect	Twigs, branches, stems, and tree boles in and above the litter.
Litter	Relative-weight	Litter is the 01 horizon or "L" layer of the floor and includes freshly fallen leaves, needles, bark flakes, cone scales, fruits, dead matted grass, and a variety of miscellaneous vegetative parts. Include cones that are more than one-half in or above the litter. If they are more than one-half below the litter, treat as duff. Omit sampling downed woody material as part of the litter because it is sampled by the planar intersect method.
Duff	Depth measurement	Duff is the 02 horizon or fermentation and humus layers of the forest floor. It lies below the litter and above mineral soil
Herbaceous plants	Relative-weight estimate	All live and dead grasses, sedges, and forbs. Dead grasses and forbs detached and fallen from their growing point should be considered litter. Some small woody plants such as bunchberry *(Cornus canadensis)*, twinflower *(Linnea borealis)*, prince's pine *(Chimaphila umbellata)*, and kinnikinnick *(Arctostaphylos uva-ursi)*, should be sampled as herbs because the shrub method is inapplicable. If desired, small woody plants can be sampled separately using an extra form.
Shrubs	Stem counts	All woody shrubs except those included in the herbaceous sample. Include common juniper *(Juniperus communis)* as a shrub.
Small conifers	Tree counts	All conifers except common juniper. Small deciduous trees such as aspen, cottonwood, and birch can be handled as tall shrubs.

Measurements

After the subplots and line transects have been established on the ground, begin recording general information at the top of the inventory form (fig. 4).

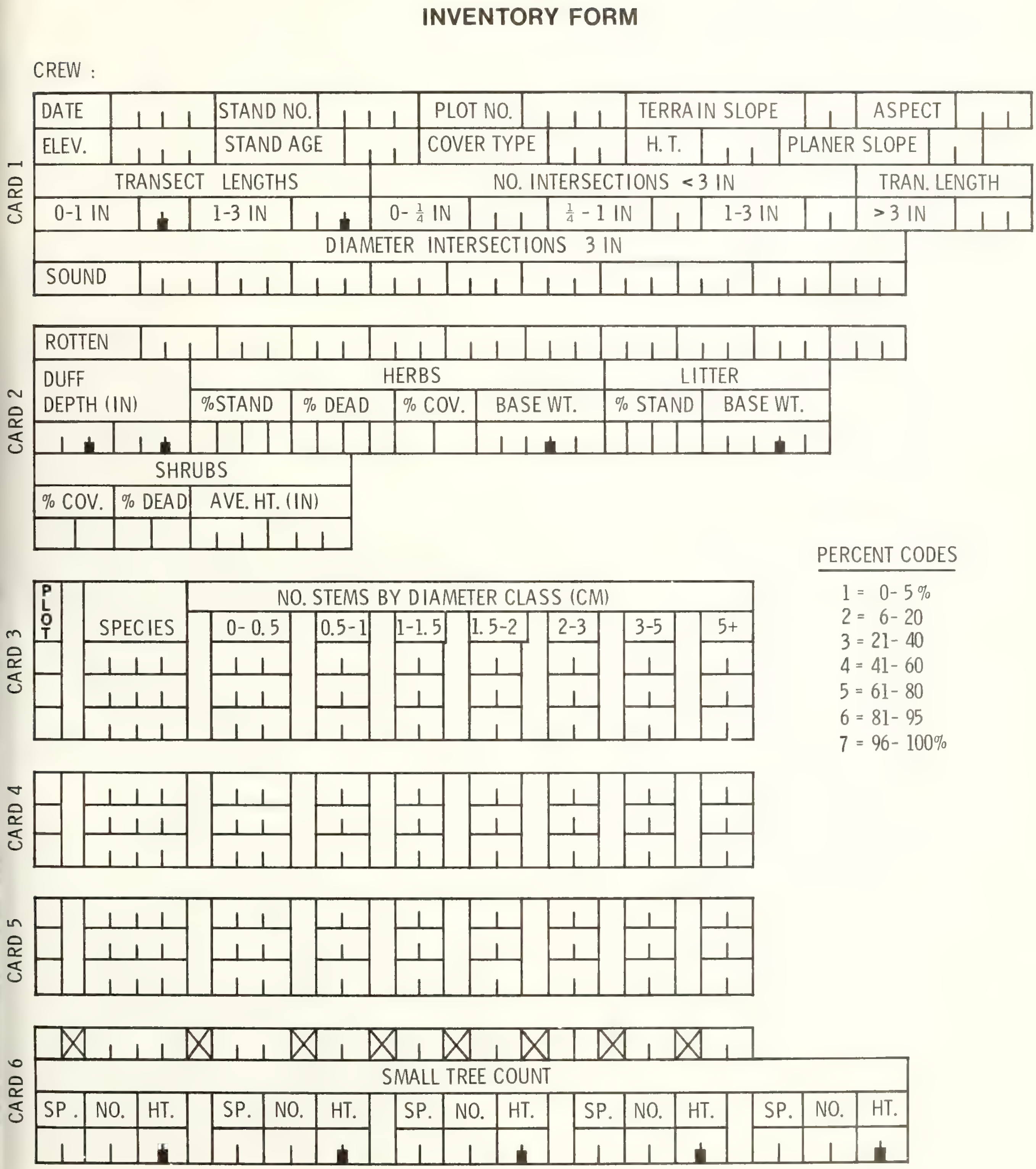

Figure 4.—Ground fuel and vegetation inventory form.

General Information:

DATE	780	STAND NO	1	PLOT NO	10	TERRAIN SLOPE	50	ASPECT	210
ELEV.	5240	STAND AGE	50	COVER TYPE	DF	H. T.	260	PLANER SLOPE	35

Step 1: Date can be recorded as month and year, or day and month.

Step 2: Identify stands and plots by consecutive number. Stand numbers can be placed on a field map for referencing locations (e.g., stand No. 1, plots numbered 1-10; stand No. 2, plots numbered 11-20).

Step 3: Determine topographic slope in percent. A Relaskop, Abney, or a clinometer is useful for measuring slope.

Step 4: Using a compass, record aspect of the area near the sample point in degrees.

Step 5: Determine elevation by an altimeter or from reading a contour map. If an altimeter is used, calibrate it daily to a known elevation.

Step 6: Determine stand age by extracting increment cores from three or four dominant or codominant trees in the stand. Take the cores at d.b.h. on the uphill side of the tree. Average the ages and enter the average on the form. Age needs to be recorded on only one plot per stand.

Step 7: Cover type is used to determine duff loading. For proper duff calculations, record the cover type that most resembles one of the following species categories (left justify the codes, see data form insert):

Cover type is most like:	Code
1. Long-needled pine (except ponderosa pine)	PP
2. Intermediate-needled conifer (except lodgepole pine) and other conifers that typically occur in mixed pine-fir types (except Douglas-fir)	LP DF
3. Predominantly short-needled conifers (except true fir, spruce, and hemlock)	Any other code

Step 8: Record habitat type using a 3-digit code. The habitat type system developed by Pfister and others (1977) is appropriate here.

Step 9: Estimate or measure the slope of the planar intersect sampling plane by sighting along the transect pole or tape previously positioned on the ground. Record this as a percentage.

Step 10: Record the transect lengths. (Refer to the discussion on sampling plane lengths.) Note on the inventory form that sampling plane lengths for 0- to 1-inch (0- to 2.5-cm) and 1- to 3-inch (2.5- to 7.6-cm) material require a decimal place.

TRANSECT LENGTHS				NO. INTERSECTIONS < 3 IN						TRAN. LENGTH	
0-1 IN	6.8	1-3 IN	10.0	0-¼ IN	33	¼-1 IN	5	1-3 IN	0	>3 IN	35

Downed Woody Material:

Less than 3-inch diameters.—This material should be measured first to avoid disturbing it and causing inaccurate estimates.

Step 1: Count the number of 0- to 0.25-inch (0- to 0.6-cm and 0.25- to 1-inch (0.6- to 2.5-cm) particles intersected by the sampling plane. This techniq involves counting intersections of woody pieces with vertical sampling planes that resemble guillotines dropped through the downed debris. The vertical plane is a plot. Consequently, in counting particle intersections, it is very important to visualize the plane passing throug one edge of the plot rod and terminating along an imaginary fixed line on the ground. Once visualized on the ground, the position of the lin should not be changed while counting particles (fig. 5).

Figure 5.—The sampling plane is exactly defined by one edge of the plot rod.

The intersections can be counted one size cla at a time or "dot tallied," which takes slightly longer than counting. The actual diameter of t particle at the point of intersection determines its size class. A go/no-go gage with openings of 0.25 inch (0.6 cm), 1 inch (2.5 cm), and 3 inches (7.6 cm) works well for training the eye to recogniz size classes. Count the 0- to 1-inch (0- to 2.5-c intersections on the 6.8-ft (2.07-m) transect (or whatever length is chosen). See tally rules for qualifying particles.

Step 2: Count the number of 1- to 3-inch (2.5- to 7.6-cm) particles. Proceed as in step 1, but use a longer sampling plane, such as 10 ft (3 m). The 50-foot tape can be used to mark the transect. Count the number of intersections of woody pieces between 1 and 3 inches (2.5 and 7.6 cm) in diameter. Refer to tally rules for qualifying particles.

Three-inch and greater diameters.—Measure or estimate the diameters of all pieces 3 inches (7.6 cm) and larger at the point of intersection with the sampling plane. Record true piece diameters to nearest whole inch regardless of angle of intersection. Record sound pieces and rotten pieces separately. For example, the data form insert shows that 5- and 6-inch sound pieces were intersected and that 4-, 10-, and 6-inch rotten pieces were intersected.

SOUND	5	6	
ROTTEN	4	10	6

Consider pieces rotten when the piece at the intersection is obviously punky or can be easily kicked apart.

A ruler laid perpendicular across a large piece of fuel works satisfactorily for measuring diameters (fig. 6). Be sure to avoid parallax in reading the ruler. See tally rules for qualifying particles.

Figure 6.—Diameters of large fuels can be estimated using a ruler laid perpendicularly across the pieces.

Tally rules.—These rules apply to pieces of all diameters:

1. Particles qualifying for tally include downed, dead, woody material (twigs, stems, branches, and bolewood) from trees and shrubs. Dead branches attached to boles of standing trees are omitted because they are not downed vegetation. Consider a particle downed when it has fallen to the ground or has been severed from its original growing point. Dead woody stems and branches still attached to standing shrubs and trees are not counted.

2. Twigs, and branches lying in the litter layer and above are counted. But they are not counted when the intersection between the central axis of the particle and the sampling plane lies in the duff (fig. 7).

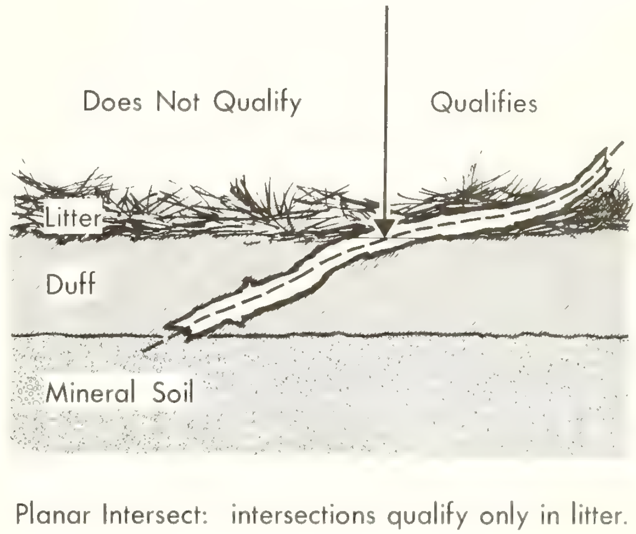

Figure 7.—Regardless of size, pieces are tallied only when intersection lies in and above the litter.

3. If the sampling plane intersects the end of a piece, tally only if the central axis is crossed (fig. 8). If the plane exactly intersects the central axis, tally every other such piece.

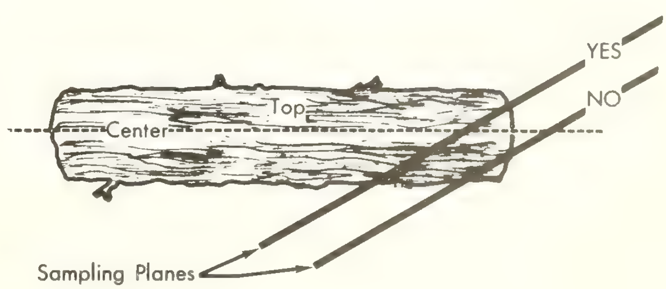

Figure 8.—An intersection at the end of a branch or log must include the central axis to be tallied.

4. Do not tally any particle having a central axis that coincides perfectly with the sampling plane. (This should rarely happen.)

5. If the sampling plane intersects a curved piece more than once, tally each intersection (fig. 9).

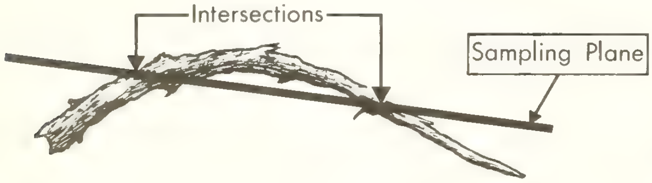

Figure 9.—Count both intersections for a curved piece.

6. Tally wood slivers and chunks left after logging. Visually mold these pieces into cylinders for determining size class or recording diameters (fig. 6).

7. Tally uprooted stumps and roots not encased in dirt. For tallying, consider uprooted stumps as tree boles or individual roots, depending on where the sampling planes intersect the stumps. Do not tally undisturbed stumps.

8. For rotten logs that have fallen apart, visually construct a cylinder containing the rotten material and estimate its diameter. The cylinder will probably be smaller in diameter than the original log.

9. Be sure to look up from the ground when sampling because downed material can be tallied up to any height. A practical upper cutoff is about 6 ft. In deep slash, however, it may be necessary to tally above 6 ft.

Duff Depth:

Step 1: Measure depth of duff to the nearest 0.1 inch, using a ruler held vertically at two points along the sampling plane: (1) 1 ft (0.3 m) from the sample point; and (2) a fixed distance of 3 to 5 ft (1 to 1.5 m) from the first measurement.

DUFF DEPTH (IN)	
1.0	0.5

Duff is the fermentation and humus layers on the forest floor. It does not include the freshly cast material in the litter layer. The top of the duff is where needles, leaves, and other castoff vegetative material have noticeably begun to decompose. Often the color of duff differs from the litter above. Individual particles usually will be bound by fungal mycelium. When moss is present, the top of the duff is just below the green portion of the moss. The bottom of the duff is mineral soil.

Carefully expose a profile of the forest floor for the measurement (fig. 10). A knife or hatchet helps but is not essential. Avoid compacting or loosening the duff where the depth is measured. Measure duff depth after sampling the downed woody material to avoid disturbing the downed woody material along the sampling plane.

Figure 10.—Measure duff depth along an exposed profile of the forest floor from the top of the mineral soil to the bottom of the 01 horizon.

When stumps, logs, and trees occur at the point of measurement, offset 1 ft (0.3 m) perpendicular to the righ side of the sampling plane. Measure through rotten logs whose central axis is in the duff layer (fig. 11).

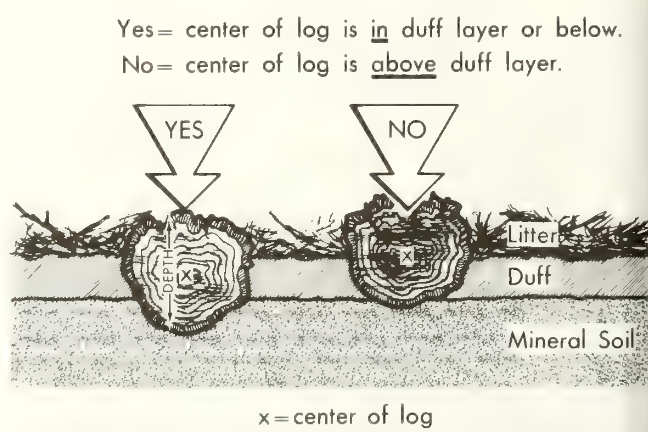

Figure 11.—Duff depth is measured through a rotten log when its central axis lies in or below the duff.

Herbaceous Vegetation and Litter:

Step 1: View all four subplots and judge which one has the greatest weight of herbaceous plants, both live and dead. See table 2 for discussion of plants to be sampled here. The subplot picked with the greatest weight is the standard subplot and is recorded as an 8.

Rate the amount of herbaceous plants on the remaining three subplots as a percentage of that on the standard subplot using the following codes established for these procedures:

Percent	**Code**
0-5	1
6-20	2
21-40	3
41-60	4
61-80	5
81-95	6
96-100	7

HERBS										
%STAND				% DEAD				% COV.		BASE WT.
1	2	3	4	1	2	3	4	1	2	
7	8	5	3	1	1	2	1	5	6	12.07

Step 2: For each individual subplot, ocularly estimate the percentage of herbaceous vegetation that is dead. Use the established percentage code.

Step 3: Ocularly estimate, in percentage, cover of herbaceous vegetation on subplots 1 and 2. (Percentage of cover is the percentage of subplot area covered by a vertical projection of herbaceous material.) Record cover using the established codes.

Step 4: View the right half of all four subplots and judge which one has the greatest quantity of litter. Occasional probing of the litter may help in judging quantities. Be sure to examine only material qualifying as litter. See table 2 for material to be included as litter. Record the standard litter subplot with an 8.

Rate the quantity of litter on the remaining three subplots as a percent of that on the standard subplot. Be sure to view only the right half of each subplot. Use the established codes.

LITTER				
% STAND				BASE WT.
1	2	3	4	
7	7	8	3	19.10

Step 5: Clip the herbaceous vegetation from the herb standard subplot and place in a paper bag. Collect litter from the litter standard subplot (right half only) and place in a paper bag. Label bags with date, stand number, plot number, and litter or herb.

The samples should be ovendried at 95° C for a period of 24 hours. Record the ovendry weights, labeled as base weights on the inventory form, to the nearest 0.01 gram. Gunnysacks work well for transporting and storing samples. Airtight containers, such as plastic sacks, may promote decay.

Shrubs:

Step 1: Shrubs are tallied on the two ¼-milacre subplots (fig. 2). Using a 1.86-ft (57-cm) rod (radius of ¼-milacre plot), swing around the subplot center parallel to the ground and note the species that occur. Within each subplot, ocularly estimate percent cover of all shrubs together, both live and dead, according to the established percentage classes.

SHRUBS					
% COV.		% DEAD		AVE. HT. (IN)	
1	2	1	2		
4	3	1	1	24	12

Step 2: Ocularly estimate the percentage of shrub biomass that is dead according to the established percentage classes.

Step 3: Measure the height of shrubs within each subplot from the forest floor to what appears as the average top. Record to the nearest whole inch.

Step 4: On each subplot, count the number of stems by species and the following basal diameter classes:

0 to 0.2 inch (0 to 0.5 cm)
0.2 to 0.4 inch (0.5 to 1.0 cm)
0.4 to 0.6 inch (1.0 to 1.5 cm)
0.6 to 0.8 inch (1.5 to 2.0 cm)
0.8 to 1.2 inches (2.0 to 3.0 cm)
1.2 to 2.0 inches (3.0 to 5.0 cm)
Over 2.0 inches (5.0 cm)

Determine basal diameters above the root crown or above the swelling of the root crown, which is usually within 1 or 2 inches above the top of the litter. A go/no-go gage is helpful for checking

diameters (fig. 12). The basal diameter classes are identified on the data form in centimeter units because they can be visualized more easily than inches for estimating shrub diameters.

Figure 12.—A go/no-go gage used for tallying the number of shrub stems by basal diameter classes.

PLOT	SPECIES	NO STEMS BY DIAMETER CLASS (CM) 0-0.5	0.5-1	1-1.5	1.5-2	2-3	3-5	5+
1	CEVE	13	4					
1	PHMA	7	3	2				
1	BERE	2						
1	SYAL	8	0	3				
2	BERE	7						
2	LOW	12						

Record species using the abbreviations in the following tabulation. If a sampled species is not in the list, record it as a low, medium, or high shrub, depending on the group it most resembles. Whenever LOW or MED abbreviations are used, left justify them (see insert of inventory form).

Shrubs	**Abbreviation**
Low shrubs:	
Snowberry (*Symphoricarpos albus*)	SYAL
Blue huckleberry (*Vaccinium globulare*)	VAGL
Grouse whortleberry (*Vaccinium scoparium*)	VASC
Wild rose (*Rosa* spp.)	ROSA
Gooseberry (*Ribes* spp.)	RILA
White spirea (*Spirea betulifolia*)	SPBE
Oregon grape (*Berberis repens*)	BERE
Thimbleberry (*Rubus parviflorus*)	RUPA
Red raspberry (*Rubus idaeus*)	RUID
Combined species	LOW
Medium shrubs:	
Ninebark (*Physocarpus malvaceus*)	PHMA
Smooth menziesia (*Menziesia ferruginea*)	MEFE
Utah honeysuckle (*Lonicera utahensis*)	LOUT
Oceanspray (*Holodiscus discolor*)	HODI
Evergreen ceanothus (*Ceanothus velutinus*)	CEVE
Mockorange (*Philadelphus lewisii*)	PHLE
Russet buffaloberry (*Shepherdia canadensis*)	SHCA
Big sagebrush (*Artemisia tridentata*)	ARTR
Common juniper (*Juniperus communis*)	JUCO
Combined species	MED
High shrubs:	
Serviceberry (*Amelanchier alnifolia*)	AMAL
Mountain maple (*Acer glabrum*)	ACGL
Mountain ash (*Sorbus scopulina*)	SOSC
Mountain alder (*Alnus sinuata*)	ALSI
Redosier dogwood (*Cornus stolonifera*)	COST
Willow (*Salix* spp.)	SASC
Chokecherry (*Prunus virginiana*)	PRVI
Combined species	HIGH

Small trees

SMALL TREE COUNT SP	NO	HT.	SP	NO.	HT.	SP.	NO.	HT.	SP.	NO.	HT.	SP.	NO.	HT.
DF	3	9.5	LP	3	1.0	L	1	0.5						

Delineate the plot by swinging the 6.8-ft rod about the sample point pin and parallel to the slope. Within the 1/300-acre plot, count the number of trees less than 10 ft (3 m) in height by species. Record the number of trees within each species and average their height to the nearest 0.5 ft. To avoid the potential of a substantial bias however, do not average heights differing by more than 5 ft. If trees of the same species differ by more than 5 ft in height, record them separately on the data form. If more than five species are identified, consolidate similar species. Tally only individual trees that have survived one growing season, are free to grow, have good coloration, and have root systems in mineral soil.

Use the following tree codes (single letter codes are left justified; see insert of inventory form):

Species	Code
Subalpine fir (*Abies lasiocarpa*)	AF
Douglas-fir (*Pseudotsuga menziesii*)	DF
Western redcedar (*Thuja plicata*)	C
Grand fir (*Abies grandis*)	GF
Juniper (*Juniperus scopularum*)	J
Western larch (*Larix occidentalis*)	L
Lodgepole pine (*Pinus contorta*)	LP
Ponderosa pine (*Pinus ponderosa*)	PP
Western white pine (*Pinus monticola*)	WP
Whitebark or limber pine (*Pinus albicaulis/ Pinus flexilis*)	WL
Engelmann spruce (*Picea engelmannii*)	S
Western hemlock (*Tsuga heterophylla*)	WH
Mountain hemlock (*Tsuga mertensiana*)	MH
Pacific yew (*Taxus brevifolia*)	Y

Field Equipment

Item	Use
1. 6.8-ft plot rod marked in 1-ft intervals (fiberglass rod, bamboo, or aluminum tubing works well)	Plot and transect layout, measure small tree and shrub heights
2. 1-ft ruler or steel pocket tape	Measure duff depth and diameter of intersected pieces
3. Go/no-go gage (can be cut from 1/16-1/8-inch sheet aluminum) or small caliper	Determine ¼-, 1-, and 3-inch diameters of downed woody pieces and 0.2-, 0.4-, 0.6-, 0.8-, 1.2-, and 2-inch basal stem diameters of shrubs
4. 1.86-ft plot rod marked in 1-inch increments (wood dowel works well)	Shrub plot layout; measure height of small trees and shrubs
5. Five chaining pins	Mark plot locations
6. Four 0.98- by 1.97-ft (inside measurement) subplot frames, four pieces of ¼-inch square aluminum rod, loosely riveted at three corners, allows frame to be placed through and under vegetation. A solid frame is difficult to place without bias.	Sample herbaceous vegetation and litter
7. Hand compass	Measure aspect. Locate sample points
8. Relaskop, Abney, or clinometer	Measure slope
9. Altimeter	Measure elevation
10. Increment borer	Determine tree age
11. 50-ft tape (reel up cloth works best)	Delineate sampling plane
12. Gaming die or watch with second hand	Orient sampling plane
13. Paper bags (size 10 or 12) and rubber bands	Collect herb and litter samples
14. Grass clippers	Clip subplots
15. Clipboard, forms, maps, and pencils	Record data
16. Pack, map tube	Carry equipment. Map tube keeps small rods and subplot frames together.

Sampling can be completed without a compass, slope instrument, or altimeter. If only a portion of the vegetation is to be sampled, other equipment may be unnecessary.

Calculations

The calculations of fuel loadings, biomass, and other inventoried properties are straightforward but detailed. To facilitate analysis, a computer program that calculates means, standard deviations, and standard errors as a percentage of means for the sampled properties is displayed in appendix III. An example of the program output is shown in figure 13. Loadings are calculated for land projected to a horizonal plane. The data can be readily analyzed using a desk calculator. The following discussion explains how average biomass and fuel loadings can be calculated.

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HABITAT TYPE CODE 260

********** FUEL LOADING SUMMARY **********

(FOR 64 PLOTS)

SIZE CLASS	LOADING IN OVEN-DRY POUNDS/ACRE AVERAGE		STD-DEV	%ERROR	KG/SQ-M
0-.25		112.	218.	24.3	.013
.25-1		1014.	1867.	23.0	.114
LITTER		830.	723.	10.9	.093
DEAD HERBS		351.	339.	12.1	.039
FINES	2308.		2076.	11.2	.259
1-3		2678.	4406.	20.6	.300
LESS THAN 3	4986.		5457.	13.7	.559
3+ TOTAL	18519.		39346.	26.6	2.076
SOUND 3-6		6245.	6357.	12.7	.700
SOUND 6-10		4197.	8156.	24.3	.470
SOUND 10-20		1456.	6715.	57.7	.163
SOUND 20+		4757.	38059.	100.0	.533
3+ SOUND TOTAL	16654.		39060.	29.3	1.867
ROTTEN 3-6		860.	1517.	22.1	.096
ROTTEN 6-10		513.	2350.	57.3	.057
ROTTEN 10-20		492.	3936.	100.0	.055
ROTTEN 20+		0	0	0	0
3+ ROTTEN TOTAL	1865.		5000.	33.5	.209
DUFF		12875.			1.443
DEAD SHRUB		64.	171.	23.5	.007
DEADFUEL LOAD	36444.		52161.	17.9	4.085
LIVE HERBS		1132.	957.	10.6	.127
LIVE SHRUB		1363.	3971.	25.7	.153
TREE NEEDLES		0.	2.	48.1	.000
0-.25		0.	1.	48.1	.000
.25 +		0.	2.	48.1	.000
TOTAL TREE	1.		4.	48.1	.000
TOTAL LOAD	38940.		52345.	16.8	4.365

********** DEPTH (INCHES) **********

	AVERAGE	MINIMUM	MAXIMUM	STD-DEV
DUFF	.38	0	6.50	.95
SHRUB	22.20	0	96.00	16.97

Figure 13.—Output summary from computer program FUELS which analyzes the inventoried data in figure 4.

HABITAT TYPE CODE 260

********** TOPOGRAPHIC CONDITIONS **********

	AVERAGE	MINIMUM	MAXIMUM	STD-DEV
SLOPE	20.5	7.0	53.0	12.32
ASPECT	171.0			
ELEVATION	4448.	3920.	5250.	395.3

******* AVERAGE LIVE AND DEAD SHRUB LOADINGS IN POUNDS/ACRE *******
(FOR 104 PLOTS)

PECIES	SIZE CLASS IN CENTIMETERS 0-.5	.5-1	1-1.5	1.5-2	2-3	3-5	5+	TOTAL
ERVICEBERRY	12.0	33.6	59.8	31.6	0	0	0	137.0
TN. MAPLE	57.2	151.8	137.2	0	0	0	0	346.2
OGWOOD	6.1	24.2	108.0	0	0	0	0	138.3
TN. WILLOW	1.2	2.2	4.6	0	0	0	0	8.0
INEBARK	84.3	122.3	38.4	0	0	0	0	245.0
NOWBERRY	58.3	54.1	4.7	0	0	0	0	117.1
UCKLEBERRY	12.2	8.5	0	0	0	0	0	20.7
OSE	25.3	25.0	239.0	0	0	0	0	289.3
OOSEBERRY	.1	3.4	0	0	0	0	0	3.6
. SPIREA	112.9	13.9	0	0	0	0	0	126.8
REGONGRAPE	7.9	.9	0	0	0	0	0	8.8
HIMBLEBERRY	18.2	52.7	245.6	0	0	0	0	316.5
OTAL	395.8	492.6	837.2	31.6	0	0	0	1757.1

***** PERCENTAGE ESTIMATES ********* 3+ VOLUME AND DIAMETER *****

SHRUB %COVER	SHRUB %DEAD	HERBS %COVER	HERBS %DEAD	SOUND CU-FT	SOUND AVG.DIA	ROTTEN CU-FT	ROTTEN AVG.DIA
34.3	4.4	49.8	27.6	667.	4.68	100.	4.87

********** SMALL TREES **********

SPECIES	TREES/ACRE	AVG.HT.FT.
LP	122.	.56
TOTAL	122.	

Figure 13.—(con.)

Downed Woody Material

Besides the inventoried data on number of intersections and piece diameters, calculations of loading require estimates of specific gravity, average diameters of particle size and classes, and nonhorizontal correction factors. Precision of the calculated loadings depends on determination of these constants. Detailed instructions for computing loading are described by Brown (1974b).

When inventorying large areas that hold many species, it is practical to use values based on a composite of species for specific gravity, average particle diameters, and nonhorizonal correction factors. The following formulas for calculating loading assume fixed values for these variables:

1. 0- to 0.25-inch (0- to 0.6-cm) class: $\bar{w} = 190.7\ nc/(Nl)$ (1)
2. 0.25- to 1-inch (0.6- to 2.5-cm) class: $\bar{w} = 3{,}650\ nc/(Nl)$ (2)
3. 1- to 3-inch (2.5- to 7.6-cm) class: $\bar{w} = 29{,}040\ nc/(Nl)$ (3)
4. 3+-inch (7.6+-cm) sound: $\bar{w} = 9{,}312\ d^2c/(Nl)$ (4)
5. 3+-inch (7.6+-cm) rotten: $\bar{w} = 6{,}984\ d^2c/(Nl)$ (5)

where:

$\bar{w}$ = average loading, ovendry basis, lb/acre
n = total number intersections by particle class per stand
d^2 = sum of diameters (inches squared for all intersected pieces per stand, inches^2
c = planar slope correction factor
N = number of sample points
l = length of sampling plane.

The slope correction factor is

$$c = \sqrt{1 + \left(\frac{\text{percent slope of sampling plane}}{100}\right)^2} \qquad (6)$$

When n, d^2, and c are totaled separately for a stand, a bias that is probably small could result. Summing (n) • (c) or d^2 • (c) over all plots would eliminate the biases.

Litter and Herbaceous Vegetation

Litter loading is calculated as:

$$\bar{w} = 24.78 \sum_{i=1}^{N} c_i w_i (1 + P_2 + P_3 + P_4)_i / N \qquad (7)$$

where:

c = topographic slope correction
w = weight on standard plot, grams
P = fraction of weight on standard plot for individual subplots
i = index for sample points.

Herbaceous vegetation loading is calculated as:

$$\bar{w} = 12.39 \sum_{i=1}^{N} c_i w_i (1 + P_2 + P_3 + P_4)_i / N \qquad (8)$$

To calculate the amount of dead herbaceous vegetation, the fraction of weight on the standard plot is multiplied by the fraction dead:

$$\bar{w} = 12.39 \sum_{i=1}^{N} c_i w_i (D_1 + P_2 D_2 + P_3 D_3 + P_4 D_4)_i / N \qquad (\text{(}$$

where:

D = fraction of dead on individual subplots.

Use the midpoints of the established percentage classes for fractions in the calculations.

The slope correction may be handled differently depending on the amount of slope and its variability. If slope is less than about 40 percent, the correction is 8 percent and, for practical purposes, could be ignored.

If the slope in a stand is steep and uniform, the slope correction factor can be multiplied times the average stand loading rather than times the loading at each sample point. This also applies to calculation of shrub loadings.

Shrubs

Shrub loading is calculated by summing the weights o individual stems by species:

$$\bar{w} = 8.8185 \sum_{ijk}^{N,2,7} c_i (s_k w_k)_{ij} / (2N) \qquad (1$$

where:

s = number of stems per basal diameter class
w = weight per stem of foliage and wood by basal diameter class (table 3), grams
j = index for shrub subplots
k = index for basal diameter classes.

Dead shrub weight is calculated by multiplying the frac tion dead on each subplot by estimated weight per subplot. Thus,

$$\bar{w} = 8.8185 \sum_{ijk}^{N,2,7} c_i D_{ij} (s_k w_k)_{ij} / (2N) \qquad (1$$

where:

D = fraction of dead shrubs per subplot.

Weight per stem is summarized in table 3 based on data by Brown (1976). Brown also presents relationships for estimating foliage and stemwood separately.

Duff

Duff loading is calculated as:

$$\bar{w} = 3{,}630\ Bd \qquad (1.$$

where:

B = bulk density, lb/ft^3
d = average duff depth for a stand, inches.

Bulk densities can be obtained from table 1, the condensation of table 1 in the text, or from other sources

Small Trees

Small tree loadings can be computed by summing the weights of individual sample trees. The simplest approac is to first construct a table showing the total number of sample trees per stand by species and 1-ft height increments. Loading for each species can then be calculated by:

$$\bar{w} = 300 \sum_{i=1}^{10} N_h w_h / N \qquad (13)$$

vhere:

N_h = total number sampled trees by height class per stand

w_h = weight per tree by height class, pounds

i = index for height classes.

Weights per tree as determined by Brown (1978) are summarized in table 4. The 300 in equation (13) expands 1/300-acre plot estimates to a per-acre basis. If other plot sizes are used, the 300 should be replaced with appropriate expansion factors.

The procedures in this publication permit estimation of total biomass and fuel loading of forest floor and understory vegetation. The estimates are appropriate for intensive land management and studies involving biomass and forest fuels.

able 3.—Total aboveground weight of shrubs by basal diameter classes

	Stem basal diameters (cm)						
pecies	0-0.5	0.5–1.0	1.0–1.5	1.5–2.0	2–3	3–5	5–6
	Grams						
ow shrubs							
Snowberry	2.8	17.0	54.6	118.0	226	—	—
Blue huckleberry	1.0	12.0	59.8	173.0	531	—	—
Grouse whortleberry	2.2	12.1	36.3	74.8	161	—	—
Wild rose	1.9	16.9	70.0	178.0	480	—	—
Gooseberry	1.7	20.0	98.4	281.0	856	—	—
White spirea	2.2	17.4	65.7	158.0	399	—	—
Oregon grape	2.0	10.7	31.3	63.2	133	—	—
Thimbleberry	2.1	15.5	56.6	133.0	328	—	—
Red raspberry	2.0	19.3	83.3	218.0	605	—	—
Combined species	2.0	16.4	64.1	157.0	407	—	—
ledium shrubs							
Ninebark	3.9	19.9	74.1	176.0	442	1 150	—
Smooth menziesia	1.2	8.7	43.6	126.0	387	1 240	—
Utah honeysuckle	2.9	18.5	83.8	226.0	650	1 940	—
Oceanspray	2.7	18.1	85.3	237.0	698	2 140	—
Evergreen ceanothus	2.9	17.3	74.1	193.0	533	1 530	—
Mock orange	2.6	17.2	79.6	218.0	636	1 930	—
Russet buffaloberry	3.6	16.5	56.5	127.0	300	730	—
Big sagebrush	3.0	12.4	38.9	82.7	184	422	871
Common juniper	7.9	31.4	96.8	203.0	445	1 010	—
Combined species	2.6	15.8	67.8	177.0	490	1 410	—
igh shrubs							
Serviceberry	3.4	16.1	70.2	185.0	519	1 510	3 840
Mountain maple	4.0	17.2	70.0	177.0	417	1 310	3 180
Mountain ash	2.5	11.5	50.2	132.0	370	1 070	2 720
Mountain alder	4.5	16.7	58.8	135.0	325	809	1 790
Redosier dogwood	4.8	18.9	70.5	168.0	420	1 090	2 500
Willow	2.8	12.3	50.4	128.0	342	950	2 320
Chokecherry	2.7	12.9	57.4	153.0	434	1 280	3 290
Combined species	3.6	15.4	60.9	151.0	394	1 070	2 560

Table 4.—Weight per tree of aboveground foliage, bark, and wood by 1-ft tree height increments

Species	Height									
	1	2	3	4	5	6	7	8	9	10
	Pounds									
DF,PP,S,AF	0.03	0.20	0.56	1.18	2.09	3.33	4.94	6.95	9.39	12.30
WP,GF,WL	.06	.25	.61	1.15	1.87	2.78	3.88	5.19	6.71	8.43
C,L,LP	.02	.13	.34	.69	1.17	1.82	2.64	3.65	4.84	6.24
WH	.01	.05	.16	.35	.64	1.05	1.60	2.31	3.18	4.24

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APPENDIX I
APPLICABILITY OF TECHNIQUES

Some techniques can be applied more widely than others without any known loss of accuracy. Limitations in applying the techniques can be inferred from knowing the sources of data underlying their development. Applicability of the techniques is as follows:

1. **Downed woody material** - Average diameters of size classes less than 3 inches (7.6 cm) are based on an average of major western tree species. The estimates of this material are robust and should be reasonably accurate in coniferous forests. More precision can be obtained using the procedures in Brown (1974b). No limitations are built into the technique for material greater than 3 inches (7.6 cm) in diameter.
2. **Litter and herbaceous vegetation** - The relative estimate technique has no geographic restrictions.
3. **Duff** - Estimates of depth apply without geographic limitations. However, the duff bulk densities used to determine loading are based on a small amount of data from western coniferous forests. Although the loading estimates are probably applicable throughout coniferous forests in the United States and perhaps elsewhere, they should be viewed as crude approximations.
4. **Shrubs** - Biomass estimates are based on data from shrubs in western Montana and northern Idaho. The weight relationships for low, medium, and high shrubs may be used to estimate biomass of any species. Accuracy of these relationships outside of the Northern Rocky Mountains is unknown.
5. **Small trees** - Estimates of biomass for trees less than 10 ft (3 m) in height are based on data from western Montana and northern Idaho for Engelmann spruce, western hemlock, western white pine, whitebark pine, ponderosa pine, lodgepole pine, grand fir, western redcedar, western larch, Douglas-fir, and subalpine fir (Brown 1978). Equating a species not listed to one of the above may provide reasonable estimates of biomass; however, accuracy of this substitution is unknown.

APPENDIX II
SAMPLING PROCEDURES

Use of these procedures in the Selway-Bitterroot Wilderness (Habeck and Mutch 1973) provided a basis for determining desirable sampling intensities as shown by the coefficients of variation in table 5. Number of sample points can be calculated for any chosen percent error (Avery 1967) from:

$$n = \left[\frac{cv}{\text{percent error}}\right]^2 \tag{14}$$

where:

cv = (standard deviation/mean) 100

Percent error = (standard error of mean/mean)100.

Figure 14 shows sampling intensities for herbs and fine fuels, cv = 80; litter, cv = 100; and shrubs, cv = 140. Fine fuels consist of litter, herbs, and 0- to ¼-inch (0- to 0.6-cm) downed woody material. The sampling intensities for fines agree with those in Brown (1974b) for 0- to 1-inch (0- to 2.5-cm) downed woody material. Generally, for a given level of precision, estimates for combined vegetative categories require fewer sample points than for individual vegetative categories.

A scattergram of mean estimates and percent errors showed a lack of correlation. Thus, figure 14 should apply to loadings ranging from light to heavy. Cover types appeared to slightly influence coefficients of variation (table 5). For example, for a given percent error, fewer sample points are required to estimate litter in ponderosa pine and Douglas-fir than in the grand fir and spruce-fir types. This seems reasonable because litter is more uniform in ponderosa pine and Douglas-fir stands. For the most part, however, differences among cover types in table 5 provided little guidance on sampling intensities. Advance knowledge about the uniformity of fuels should be more useful in deciding upon sampling intensities than cover type.

Coefficients of variation for shrubs varied considerably from stand to stand. High coefficients of variation were due to occasional plots falling in clumps of large-sized shrubs. The number of plots required to achieve a given percent error might easily be twofold to fourfold more or less than suggested in figure 14.

Table 5.—Average coefficients of variation from stands sampled with 10 sample points in the Selway-Bitterrott Wilderness

Cover type	Litter	Herbaceous vegetation	Fines	Shrubs	Duff	Number of stands
Ponderosa pine	93	79	73	116	104	12
Douglas-fir	91	86	72	137	79	19
Grand fir	131	75	74	160	74	19
Engelmann spruce-subalpine fir	122	81	102	168	96	13
Average	109	80	80	145	88	—

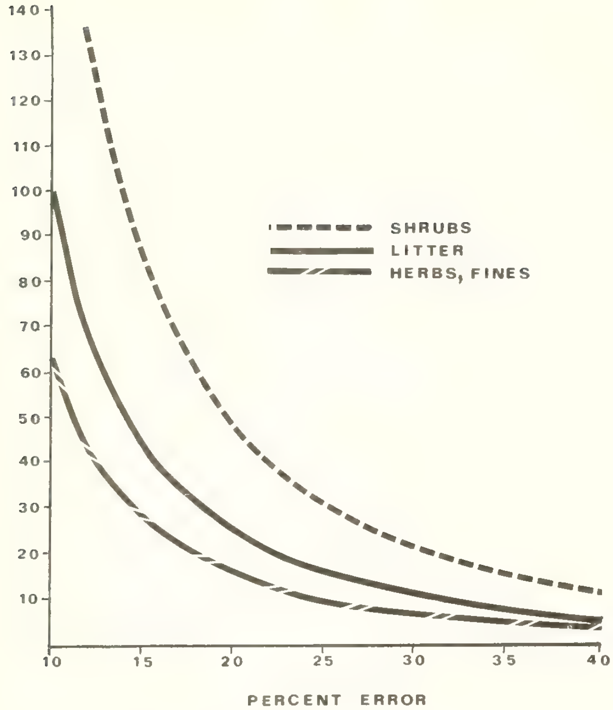

Figure 14.—Number of sample points related to percentage of error based on data from the Selway-Bitterroot Wilderness, Idaho.

Quantity of downed woody material larger than 3 inches (7.6 cm) in diameter can vary considerably with stands. As number of pieces per acre increases, variability among sample points tends to decrease and sampling effort can be reduced to achieve a given sampling precision. For large diameter pieces, the sampling plane should be long enough so that on the average, at least one intersection occurs with three-fourths or more of the planes. A large sampling variance results when many zeros are recorded for intersections. In areas where very little downed material exists, sampling planes should actually be one to several hundred feet long to provide respectable precision. As an average for coniferous cover types, use of 35- to 50-ft (10.8- to 15.2-m) sampling planes should require sampling intensities similar to litter (fig. 14).

APPENDIX III COMPUTER INSTRUCTIONS

This appendix explains how to set up and operate a computer program for calculating results from the inventory data. It includes a listing of the computer program and instructions for punching and verifying data.

ADP Program Writeup

Description

SYSTEM	STAND BIOMASS
PROGRAM	FUELS
LANGUAGE	ASCII FORTRAN V
MACHINE	PERKIN ELMER 3200
USAGE	BATCH

Purpose

This program performs calculations of the sampling results shown in figure 13. The program produces weight in pounds per acre and kilograms per square meter of forest floor duff, forest floor litter, herbaceous vegetation, shrubs, small conifers, and downed woody material. Also, estimates for live and dead vegetation by diameter size classes are furnished. This information has application in research investigations and intensive forest management.

Input

The program accepts data from the inventory form in figure 4. The input data must follow the sequence of the data form. The record order of Card 1 through Card 6 for each plot is required. The data must be on an input medium which will allow REWIND, i.e., a magnetic tape or disk file. The present program reads the parameter card from the card reader designated LU 60. The input data file is read from LU 5.

The first parameter card is a title card for the run. The second parameter card defines one of the three output options available. The options are:

1. Individual stands
2. Sorted by cover type
3. Sorted by habitat type.

All the acceptable cover type, habitat type, tree and shrub species codes are found in the text.

Output

The program will produce two pages of output (fig. 13) for each stand of input. Also, two pages of output will be produced for each cover type or habitat type.

Method

The program contains a set of constants tied to the sampling techniques described in the text: XLOAD, ZLOAD, YLOAD(1), YLOAD(2). They convert all units to tons per acre and also account for the nonhorizontal particle correction, particle density, and the $\pi^2/8$ portion of the planar intersect formula. YLIT and YGFS convert the plot weights to the proper weight units. If any variation of the sampling technique is used, these constants will require recalculation.

Runstream

As stated earlier, the inventory data must be a file on disk, tape, or other medium that allows REWIND. The parameter cards are read from the card reader. The formats are:

CARD 1	**TITLE CARD**
cc	**Description**
1-60	Free field to identify run
CARD 2	**TYPE OF RUN**
cc	**Description**
1-19	Sort desired on date, legal options are: **cc** 1 5 10 15 STAND SEPARATELY COVER TYPE HABITAT TYPE

CARD PUNCHING AND VERIFYING INSTRUCTIONS

FUNCTION *	PROGRAM NAME	
D- DUPLICATE S- SKIP V- VERIFY P- PUNCH L- LEFT JUSTIFY	PROGRAM NUMBER	DATE
	PREPARED BY	PAGE 1 of 6

CARD FIELD	COLUMNS FROM	COLUMNS TO	NO. COLS.	FUNC. *	REMARKS
STAND NO.	1	4	4	P	
PLOT NO.	5	8	4	P	
TERRAIN SLOPE	9	10	2	P	
ASPECT	11	13	3	P	
ELEVATION	14	17	4	P	
STAND AGE	18	20	3	P	
COVER TYPE	21	23	3	L	ALPHA
HABITAT TYPE	24	26	3	P	
PLANER SLOPE	27	28	2	P	
TRANSECT LENGTH (0-1)	29	30	2	P	
TRANSECT LENGTH (1-3)	31	33	3	P	
NO INTERSECTS 0-1/4 in.	34	36	3	P	
NO INTERSECTS 1/4-1 in.	37	38	2	P	
NO INTERSECTS 1-3 in.	39	40	2	P	
TRANSECT LENGTH >3 in.	41	43	3	P	
DIA. >3 in. SOUND	44	73	30	P	10 3-DIGIT NOS.
SKIP	74	79	6		
CARD NO.		80			PUNCH "1"

CARD PUNCHING AND VERIFYING INSTRUCTIONS

FUNCTION *	PROGRAM NAME	
D-DUPLICATE S-SKIP V-VERIFY P-PUNCH L-LEFT JUSTIFY	PROGRAM NUMBER	DATE
	PREPARED BY	PAGE 2 of 6

CARD FIELD	COLUMNS FROM	COLUMNS TO	NO. COLS.	FUNC. *	REMARKS
STAND NO.	1	4	4	D	
PLOT NO.	5	8	4	D	
DIA. >3 in. ROTTEN	9	38	30	P	10 3-digit nos.
DUFF DEPTH	39	44	6	P	2 3-digit nos.
HERBS % STANDARD	45	48	4	P	4 1-digit nos.
HERBS % DEAD	49	52	4	P	4 1-digit nos.
HERBS COVER	53	54	2	P	2 1-digit nos.
HERB BASE WEIGHT	55	59	5	P	
LITTER % STANDARD	60	63	4	P	4 1-digit nos.
LITTER BASE WEIGHT	64	68	5	P	
SHRUBS % COVER	69	70	2	P	2 1-digit nos.
SHRUBS % DEAD	71	72	2	P	2 1-digit nos.
SHRUBS AVERAGE HEIGHT	73	78	6	P	2 3-digit nos.
SKIP	79				
CARD NO.		80			PUNCH "2"

CARD PUNCHING AND VERIFYING INSTRUCTIONS

FUNCTION *	PROGRAM NAME	
D- DUPLICATE S- SKIP V- VERIFY P- PUNCH L- LEFT JUSTIFY	PROGRAM NUMBER	DATE
	PREPARED BY	PAGE 3 of 6

CARD FIELD	COLUMNS FROM	COLUMNS TO	NO. COLS.	FUNC. *	REMARKS
STAND NO.	1	4	4	D	
PLOT NO.	5	8	4	D	
SUB-PLOT	9		1	P	If no stems recorded do not punch these.
SPECIES	10	13	4	L	ALPHA
NO STEMS 0-0.5	14	16	3	P	
NO STEMS 0.5-5+	17	28	12	P	6 2-digit nos.
SUB-PLOT		29	1	P	
SPECIES	30	33	4	L	ALPHA
NO. STEMS 0-0.5	34	36	3	P	
NO. STEMS 0.5-5+	37	48	12	P	6 2-digit nos.
SUB-PLOT		49	1	P	
SPECIES	50	53	4	L	ALPHA
NO. STEMS 0-0.5	54	56	3	P	
NO. STEMS 0.5-5+	57	68	12	P	6 2-digit nos.
SKIP	69	79	11		
CARD NO.		80			PUNCH "3"

CARD PUNCHING AND VERIFYING INSTRUCTIONS

FUNCTION *	PROGRAM NAME	
D- DUPLICATE S- SKIP V- VERIFY P- PUNCH L- LEFT JUSTIFY	PROGRAM NUMBER	DATE
	PREPARED BY	PAGE 4 of 6

CARD FIELD	COLUMNS FROM	COLUMNS TO	NO. COLS.	FUNC. *	REMARKS
STAND NO.	1	4	4	D	
PLOT NO.	5	8	4	D	
SUB-PLOT		9	1	P	
SPECIES	10	13	4	L	ALPHA
NO STEMS 0-0.5	14	16	3	P	
NO STEMS 0.5-5+	17	28	12	P	6 2-digit nos.
SUB-PLOT		29	1	P	
SPECIES	30	33	4	L	ALPHA
NO STEMS 0-0.5	34	36	3	P	
NO STEMS 0.5-5+	37	48	12	P	6 2-digit nos.
SUB-PLOT		49	1	P	
SPECIES	50	53	4	L	ALPHA
NO STEMS 0-0.5	54	56	3	P	
NO STEMS 0.5-5+	57	68	12	P	6 2-digit nos.
SKIP	69	79	11		
CARD NO.		80	1		PUNCH "4"

CARD PUNCHING AND VERIFYING INSTRUCTIONS

FUNCTION *	PROGRAM NAME	
D- DUPLICATE S- SKIP V- VERIFY	PROGRAM NUMBER	DATE
P- PUNCH L- LEFT JUSTIFY	PREPARED BY	PAGE 5 of 6

CARD FIELD	COLUMNS FROM	COLUMNS TO	NO. COLS.	FUNC. *	REMARKS
STAND NO.	1	4	4	D	
PLOT NO.	5	8	4	D	
SUB-PLOT		9	1	P	
SPECIES	10	13	4	L	ALPHA
NO. STEMS 0-0.5	14	16	3	P	
NO. STEMS 0.5-5+	17	28	12	P	6 2-digit nos.
SUB-PLOT		29	1	P	
SPECIES	30	33	4	L	ALPHA
NO. STEMS 0-0.5	34	36	3	P	
NO. STEMS 0.5-5+	37	48	12	P	6 2-digit nos.
SUB-PLOT		49	1	P	
SPECIES	50	53	4	L	ALPHA
NO. STEMS 0-0.5	54	56	3	P	
NO. STEMS 0.5-5+	57	68	12	P	6 2-digit nos.
SKIP	69	79	11		
CARD NO.		80	1		PUNCH "5"

CARD PUNCHING AND VERIFYING INSTRUCTIONS

FUNCTION *	PROGRAM NAME	
D- DUPLICATE S- SKIP V- VERIFY	PROGRAM NUMBER	DATE
P- PUNCH L- LEFT JUSTIFY	PREPARED BY	PAGE 6 of 6

CARD FIELD	COLUMNS FROM	COLUMNS TO	NO. COLS.	FUNC. *	REMARKS
STAND NO.	1	4	4	D	
PLOT NO.	5	8	4	D	
SUB-PLOT		9	1	P	
SPECIES	10	13	4	L	ALPHA
NO. STEMS 0-0.5	14	16	3	P	
NO. STEMS 0.5-5+	17	28	12	P	6 2-digit nos.
TREE COUNT SPECIES	29	30	2	L	ALPHA
" NO.	31	32	2	P	
" HT.	33	34	2	P	
" SPECIES	35	36	2	L	ALPHA
" NO.	37	38	2	P	
" HT.	39	40	2	P	
" SPECIES	41	42	2	L	ALPHA
" NO.	43	44	2	P	
" HT.	45	46	2	P	
" SPECIES	47	48	2	L	ALPHA
" NO.	49	50	2	P	
" HT.	51	52	2	P	
" SPECIES	53	54	2	L	ALPHA
" NO.	55	56	2	P	
" HT.	57	58	2	P	
SKIP	59	79	21		
CARD NO.		80	1		PUNCH "6"

```
$BATCH
C*****************************************************************************
C
C      INPUT DATA FROM UNIT TIP
C
C      CARD NO. 1
C      COLUMN VARIABLE                   DESCRIPTION
C        1-4   ISTN       - STAND NUMBER
C        5-8   IPLT       - PLOT NUMBER
C        9-10  TRSL       - TERRAIN SLOPE IN PERCENT
C       11-13  ASPT       - ASPECT IN DEGREES
C       14-17  ELEV       - ELEVATION IN FEET
C       18-20  SAGE       - STAND AGE
C       21-23  ICVT       - COVER TYPE
C       24-26  IHBT       - HABITAT TYPE
C       27-28  PLSL       - PLANER SLOPE IN PERCENT
C       29-30  TSL1       - TRANSECT LENGTH 0-1
C       31-33  TSL3       - TRANSECT LENGTH 1-3
C       34-36  XNT1       - NUMBER OF INTERSECTS 0-1/4
C       37-38  XNT2       - NUMBER OF INTERSECTS 1/4-1
C       39-40  XNT3       - NUMBER OF INTERSECTS 1-3
C       41-43  TSL4       - TRANSECT LENGTH 3+
C       44-73  DIA(I,1) - DIAMETER 3+ SOUND (10 3-DIGIT NOS. IE.I=1,10)
C
C      CARD NO. 2
C      COLUMN VARIABLE                   DESCRIPTION
C        9-38  DIA(I,2) - DIAMETER 3+ ROTTEN (10 3-DIGIT NOS. IE.I=1,10)
C       39-44  DDP(I)     - DUFF DEPTH (2 3-DIGIT NOS. IE.I=1,2)
C       45-52  IGF(I,J) - GRASS-FORBS COVER AS PERCENT OF STANDARD
C                           I=1,4 REPLICATIONS
C                           J=1 FOR % STANDARD , J=2 FOR % DEAD
C       53-54  IGFC(I)    - PERCENT GRASS-FORB COVER
C                           I=1,2 REPLICATIONS
C       55-59  WGFB       - WEIGHT OF GRASS-FORB BASE
C       60-63  ILTS(I)    - LITTER COVER AS PERCENT OF STANDARD
C                           I=1,4 REPLICATIONS
C       64-68  WLTB       - WEIGHT OF LITTER BASE
C       69-72  IBC(I,J) - PERCENT BRUSH COVER
C                           I=1,2  REPLICATIONS
C                           J=1 FOR TOTAL COVER , J=2 FOR DEAD
C       73-78  ABRH(I)     -AVERAGE BRUSH HEIGHT
C                           I=1,2  REPLICATIONS
C
C      CARD NO. 3
C      CARDS 3,4,5
C      COLUM VARIABLE
C       10-13  ISP(I)     - BRUSH SPECIES FOR PLOT I
C       14-28  NST(I,J) - NUMBER OF STEMS BY DIAMETR CLASS J FOR PLOT I
C                           J=1,7 CLASSES
C       30-33  ISP(I)
C       34-48  NST(I,J)
C       50-53  ISP(I)
C       54-68  NST(I,J)
C              ++++++++     THIS INPUT DATA IS REPEATED 10 TIMES
C                           I=1,10
C      CARD 6
C      COLUMN VARIABLE
```

```
C       10-13 ISP(I)
C       14-28 NST(I,J)
C       29-30 ISPY(I)  - SEEDLING SPECIES CODE
C       31-32 NSTEM(I) - NUMBER OF STEMS
C       33-34 ASP(I)   - AVERAGE SPECIES HEIGHT
C       35-58 +++++++  - REPEAT 29-34
C
C
C*********************************************************************
      CHARACTER NAME*6,IICL*5,ICON*5
C
C
      DIMENSION DIA(10,2), DDP(2),  IGF(4,2), ILTS(4)
     *,
     1IBC(2,2),ABRH(2),ISP(20),NST(10,7),ISPY(4),NSTM(4),HSP(4),IGFC(2)
     2,BDC(5),EDC(4),CODE(9),YLOAD(2),TCOI(3),IICL(9),REG(7,28)
     3IFTP(5),NSP(28),STCI(2),A(7,12),B(7,16),ISPX(19),NAME(2,28)
C
      COMMON XLDS(28,20),XLD2(28,20),DEP(12,20),PCV(4,20),XNDP(8,20),X(2
     18),ADIA(2,20),XND(2,20),DEP2(2,20),SHWT(7,28,20),XN(20),DMX(2,20),
     2XNLT(20),XNGF(20),DMN(2,20),NSDL(19,20),SDLH(19,20),XDLH(19,20),TC
     30A(3,20),TCON(2,20),TCOX(2,20),TCO2(2,20),STCA(2,20),STCN(2,20),ST
     4CX(2,20),STC2(2,20)
C
      COMMON /HED/ IHEAD(15),ICLT(144),ICON(2),ILAST,KEY,XINC,NPS,IC1,IP
     1S(144),ICVT,IHBT,SAGE,IDUM1(100),IY
C
      EQUIVALENCE (BDC(2),EDC)
C
      EQUIVALENCE (TCOI(1),TRSL), (TCOI(2),ELEV), (TCOI(3),ASPT)
C
      EQUIVALENCE (STCI(1),SAGE), (STCI(2),HCRB)
      EQUIVALENCE (A(1,1),REG(1,1)),  (B(1,1),REG(1,13))
C
      DATA IICL/ 'STAND', 'COVER', 'HABIT',6* '     ' /
C
      DATA BDC/3.0, 6.0, 10.0, 20.0,999.9/
C
      DATA IFTP/1HG, 1HH, 1HS, 1HL, 1HT/
C
      DATA ISPX/'AF', 'AH', 'AP', 'B ', 'C ', 'CW', 'DF', 'GF', 'J ',
     1'L ', 'LP', 'MH', 'OH', 'PP', 'S ', 'WH', 'WL', 'WP', 'Y '/
C
      DATA A/
     * 3.44,16.06,70.19,185.4,519.2,1512.,3840.,
     * 3.95,17.16,69.97,176.6,417.4,1306.,3175.,
     * 2.48,11.52,50.19,132.3,369.8,1074.,2724.,
     * 2.72,12.92,57.43,153.4,434.7,1281.,1071.,
     * 4.47,16.67,58.75,134.7,324.6, 809.,1793.,
     * 4.79,18.92,70.50,167.7,420.1,1090.,2503.,
     * 2.82,12.29,50.37,127.6,341.6, 950.,2318.,
     * 3.93,19.86,74.06,176.2,441.6,1146.,  -1.,
     * 1.21, 8.73,43.64,125.9,387.4,1243.,  -1.,
     * 2.88,18.49,83.75,226.5,650.3,1943.,  -1.,
     * 2.69,18.11,85.27,236.6,697.9,2145.,  -1.,
     * 2.89,17.30,74.09,193.1,533.1,1529.,  -1.  /
C
```

```
      DATA B/
     * 2.61,17.21,79.62,218.4,636.5,1932.,  -1.,
     * 3.64,16.52,56.49,127.0,299.6, 730.,  -1.,
     * 3.02,12.38,38.91,82.74,184.1, 422., 871.,
     * 7.87,31.42,96.77,203.0,445.3,1006.,  -1.,
     * 2.22,12.12,36.22,74.82,161.0,  -1.,  -1.,
     * 2.79,16.99,54.59,117.8,266.1,  -1.,  -1.,
     *  .99,11.96,59.79,172.6,530.8,  -1.,  -1.,
     * 1.88,16.92,69.97,178.2,480.3,  -1.,  -1.,
     * 1.69,19.96,98.36,281.2,856.3,  -1.,  -1.,
     * 2.21,17.37,65.70,157.8,399.4,  -1.,  -1.,
     * 2.05,10.74,31.27, 63.7,133.3,  -1.,  -1.,
     * 2.08,15.47,56.56,132.9,328.5,  -1.,  -1.,
     * 2.01,19.32,83.28,218.0,604.6,  -1.,  -1.,
     * 1.99,16.41,64.08,157.2,407.0,  -1.,  -1.,
     * 2.63,15.79,67.80,177.1,489.9,1408.,  -1.,
     * 3.64,15.35,60.87,150.8,394.7,1071.,2560.  /

      DATA NSP/4HAMAL, 4HACGL, 4HSOSC, 4HPRVI, 4HALSI,
     1         4HCOST, 4HSASC, 4HPHMA, 4HMEFE, 4HLOUT,
     2         4HHODI, 4HCEVE, 4HPHLE, 4HSHCA, 4HARTR,
     3         4HJUCO, 4HVASC, 4HSYAL, 4HVAGL, 4HROSA,
     44HRILA,4HSPBE,4HBERE,4HRUPA,4HRUID,4HLOW ,4HMED ,4HHIGH /

      DATA NAME/ 'SERVIC','EBERRY','MTN. M','APLE  ','MTN. A','SH    ',
     1           'CHOKEC','HERRY ','MTN. A','LDER  ','DOGWOO','D     ',
     2           'MTN. W','ILLOW ','NINEBA','RK    ','MENIES','IA    ',
     3           'HONEYS','UCKLE ','OCEANS','PRAY  ','CEANOT','HUS   ',
     4           'MOCKOR','ANGE  ','BUFFAL','OBERRY','SAGEBR','USH   ',
     5           'JUNIPE','R     ','WHORTL','EBERRY','SNOWBE','RRY   ',
     6           'HUCKLE','BERRY ','ROSE  ','      ','GOOSEB','ERRY  ',
     7           'W. SPI','REA   ','OREGON','GRAPE ','THIMBL','EBERRY',
     8 'RASPBE','RRY   ','LOW   ','      ','MEDIUM','      ',
     9 'HIGH  ','      ' /

C *** SET ALL CONSTANTS

      IBN = 0
      IIP=5
      IN=4
      IC=6
      ACRE=43560.
      XLOAD=12651.29072
      ZLOAD=10542.74226
      YLOAD(1)=9329.86042
      YLOAD(2) = 6984.0
      YLIT=0.002276
      YGFS=0.001138
      GRAM=12.00
      CODE(1)=0.025
      CODE(2)=0.125
      CODE(3)=0.300
      CODE(4)=0.500
      CODE(5)=0.700
      CODE(6)=0.875
      CODE(7)=0.975
```

```
      CODE(8)=1.0
      CODE(9)=0.0
      ILAST=-9999
C
C *** READ IN THE TITLE CARD
C
      READ(IN,10) (IHEAD(I),I=1,15)
   10 FORMAT(15A4)
C
C *** READ IN THE CONTROL CARD
C
   20 I2=12
      READ(IN,30,END=197)
     * (ICON(I),I=1,2),(IPS(I),ICLT(I),I=1,I2),IX
   30 FORMAT(2A5,9X,12(A1,A4),A1)
      IF(ICON(1 ).EQ.'STOP ') CALL EXIT
C
C *** INTERPRET CONTROL CARD AND SET PARAMETERS
C
      NC = 1
      NPS = 1
      IC1 = 1
      DO 40 I=1,3
      IF(IICL(I).EQ.ICON(1) ) GO TO 45
   40 CONTINUE
      GO TO 50
   45 KEY=I
      IF (KEY.LE.8) GO TO 90
C
C    * CHECK FOR CONTINUATION AND READ THEM IN
C
   50 WRITE(IO,60)
   60 FORMAT (///,52H************  ERROR  **********  ERROR ************
     1// 10X,'CONTROL CARD IN ERROR  -  THE CORRECT CODES ARE STAND , HA
     2BITAT TYPE , COVER TYPE' // 30H****  PROGRAM TERMINATED  **** )
      CALL EXIT
C    * SET THE CONTROL KEY
C
   90 GO TO (170,120,120),KEY
C
C    * SLOPE, ELEVATION, ASPECT, AND STAND AGE CLASSES
C
C
C    * COVER TYPE AND HABITAT TYPE
C
  120 I2=0
C
C
C *** REWIND THE DATA TAPE
C
  170 REWIND IIP
C
C *** ZERO OUT ALL STORAGE ARRAYS
C
      CALL ZERO (20)
      IC=1
      IY = 0
```

```
*** READ IN SOME DATA

180 READ(IIP,190,END=580)
   * ISTN,IPLT,TRSL,ASPT,ELEV,SAGE,ICVT,IHBT,PLSL,TSL1,
   1TSL3,XNI1,XNI2,XNI3,TSL4,(DIA(I,1),I=1,10)
190 FORMAT(2I4,F2.0,F3.0,F4.0,F3.0,A3,I3,F2.0,F2.1,F3.1,F3.0,2F2.0,F3.
   10,10F3.0)


*** IF THIS READ MARKS END-OF-FILE ON ITP CALL OUTPUT

    IF (TSL1*TSL3*TSL4.GT.0.0) GO TO 196
    WRITE (IO,195) ISTN,IPLT,TSL1,TSL3,TSL4
195 FORMAT (1H1,10X,46H**  ERROR  *****  DATA ERROR  *****  ERROR  **,
   1//,16X,'STAND NUMBER ',I4,', PLOT NUMBER ',I4,/,18X,'0-1 TRANSECT
   2LENGTH =',F6.1,' FT',/,18X,'1-3 TRANSECT LENGTH =',F6.1,' FT',/,18
   3X,'3+  TRANSECT LENGTH =',F6.1,' FT',/,10X,'ALL TRANSECT LENGTHS M
   4UST BE GREATER THAN ZERO',//,10X,46H*********  CHECK CARD AND RESU
   5BMIT   *********)
197 CALL EXIT
196 IF (ASPT.GE.360.0) ASPT=ASPT-360.0

*** READ IN THE REMAINING 5 CARDS OF DATA SET

    READ(IIP,200) (DIA(1,2),I=1,10),(DDP(I),I=1,2),((IGF(I,J),I=1,4),J
   1=1,2),IGFC,WGFB,(ILTS(I),I=1,4),WLTB,((IBC(I,J),I=1,2),J=1,2),(ABR
   2H(I),I=1,2),(ISP(I),(NST(I,J),J=1,7),I=1,10),(ISPY(I),NSTM(I),HSP(
   1I),I=1,4)

200 FORMAT(8X,10F3.0,2F3.1,10I1,F5.2,4I1,F5.2,4I1,2F3.0 /
   *                                                    8X,3(1X,A4,I3,6I
   12)/8X,3(1X,A4,I3,6I2)/8X,3(1X,A4,I3,6I2)/8X,1X,A4,I3,6I2,4(A2,I2,F
   32.1) )


*** SET PARAMETERS BASED ON DESIRED ACTION

    GO TO (210,250,260),KEY

  * STANDS SEPERATE

210 IF (ILAST.EQ.ISTN) GO TO 330
    IF (ILAST.EQ.-9999) GO TO 220
    CALL OUTPUT(NC,IBN,ISPX,NAME,IO)
    IBN = 0
    IY = 0
    CALL ZERO (NC)
220 ILAST=ISTN
    GO TO 330

  * COVER TYPE

250 IK=ICVT
    GO TO 270

  * HABITAT TYPE
```

```
C
  260 IK=IHBT
  270 DO 280 I=IC1,I2
      IF (IK.EQ.ICLT(I)) GO TO 290
  280 CONTINUE
      IF (IC1.GT.1.OR.I2.GE.144) GO TO 180
      I2=I2+1
      ICLT(I2)=IK
      NPS=I2
      IF (I2.GT.20) GO TO 180
      IC = I2
      NC = I2
      GO TO 330
  290 IC=I-IC1+1
      IF (IC.GT.20) GO TO 180
C *** CALCULATE PLANER AND TERRAIN SLOPE CONSTANTS
C
  330 PSLP=SQRT(1.0+(PLSL/100.0)**2.0)
      TSLP=SQRT(1.0+(TRSL/100.0)**2.0)
C
C *** CALCULATE THE LOAD IN POUNDS/ACRE FOR ALL SIZE CLASSES
C
C   * FIRST SET MULTIPLICATION CONSTANTS BASED ON COVER TYPE
C
      DO 333 IJJ=1,19
      IF(ISPX(IJJ).EQ.ICVT) GO TO 336
  333 CONTINUE
      IJJ = 20
  336 CALL LOOK(IJJ,A1,A2,A3)
C
C
C   * LOAD CASE 1:  0-1/4
C
      X(1)=XLOAD*A1*XNI1*PSLP/TSL1
C
C   * LOAD CASE 2:  1/4-1
C
      X(2)=XLOAD*A2*XNI2*PSLP/TSL1
C
C   * LOAD CASE 6:  1-3
C
      X(6)=ZLOAD*A3*XNI3*PSLP/TSL3
C
C   * LOAD CASE 9-12:  3+ SOUND BY SIZE CLASS
C   * LOAD CASE 14-17:  3+ ROTTEN BY SIZE CLASS
C
      DO 360 L=1,2
      XX=0.0
      DO 350 J=1,4
      SMD2=0.0
      DO 340 I=1,10
      IF (DIA(I,L).LT.BDC(J).OR.DIA(I,L).GE.EDC(J)) GO TO 340
      SMD2=SMD2+DIA(I,L)*DIA(I,L)
      ADIA(L,IC)=ADIA(L,IC)+DIA(I,L)
      XND(L,IC)=XND(L,IC)+1.0
  340 CONTINUE
      K=J+5*L+3
```

```
   X(K)=YLOAD(L)*SMD2*PSLP/TSL4
   XX=XX+X(K)
50 CONTINUE

 * LOAD CASE 13:  3+ SOUND TOTAL
 * LOAD CASE 18:  3+ ROTTEN TOTAL

   K = K+1
   X(K) = XX
60 CONTINUE
   IF(WLTB.EQ.0.0) GO TO 380
   XX=0.0
   DO 370 I=1,4
   J=ILTS(I)
   IF (J.LE.0) J=9
   XX=XX+CODE(J)
70 CONTINUE
   X(3)=YLIT*ACRE*WLTB*XX*TSLP/4.0
   XNLT(IC)=XNLT(IC)+1.0
   GO TO 390
80 X(3)=0.0

 * LOAD CASE 4:  DEAD GRASS-FORBS
 * LOAD CASE 22:  LIVE GRASS-FORBS

90 XX = 0.0
   XY = 0.0
   YY = 0.0
   YX = 0.0
   IF (WGFB.EQ.0.0) GO TO 410
   DO 400 I=1,4
   J=IGF(I,1)
   K=IGF(I,2)
   IF (J.LE.0) J=9
   IF (K.LE.0) K=9
   YY=YY+CODE(K)
   YX=YX+CODE(J)
   CON=CODE(J)*CODE(K)
   XX=XX+CODE(J)-CON
   XY=XY+CON
00 CONTINUE
   X(22)=YGFS*ACRE*WGFB*XX*TSLP/4.0
   X(4)=YGFS*ACRE*WGFB*XY*TSLP/4.0
   XNGF(IC)=XNGF(IC)+1.0
   GO TO 420
10 X(4)=0.0
   X(22) = 0.0

 * LOAD CASE 19:  DUFF

20 CON = 10.0
   IF(ICVT.EQ.3HPP ) CON = 5.0
   IF(ICVT.EQ.3HLP .OR.ICVT.EQ.3HDF ) CON = 8.0
   DEPDF=(DDP(1)+DDP(2))/2.0
   X(19)=CON*DEPDF*ACRE/GRAM
   X(5) = X(1)+X(2)+X(3)+X(4)
   X(7) = X(5) + X(6)
```

```
      DEP(1,IC)=DEP(1,IC)+DEPDF
      DEP2(1,IC)=DEP2(1,IC)+DDP(1)*DDP(1)+DDP(2)*DDP(2)
      DO 430 I=1,2
      IF (DMX(1,IC).LT.DDP(I)) DMX(1,IC)=DDP(I)
      IF (DMN(1,IC).GT.DDP(I)) DMN(1,IC)=DDP(I)
  430 CONTINUE


      IF(ABRH(1).GT.0) IBN = IBN + 1
      IF(ABRH(2).GT.0) IBN = IBN + 1
      DEP(2,IC) = DEP(2,IC) + (ABRH(1) + ABRH(2))
      DEP2(2,IC)=DEP2(2,IC)+ABRH(1)*ABRH(1)+ABRH(2)*ABRH(2)
      DO 460 I=1,2
      IF (DMX(2,IC).LT.ABRH(I)) DMX(2,IC)=ABRH(I)
      IF (DMN(2,IC).GT.ABRH(I)) DMN(2,IC)=ABRH(I)
  460 CONTINUE
C     * PERCENT CASE 1,2:  TOTAL,DEAD BRUSH COVER
      DO 470 I=1,2
      J=IBC(1,I)
      K=IBC(2,I)
      IF (J.EQ.0) J=9
      IF (K.EQ.0) K=9
      PD=(CODE(J)+CODE(K))/2.0
      PCV(I,IC)=PCV(I,IC)+PD
  470 CONTINUE
C
C     * PERCENT CASE 3,4:  TOTAL,DEAD GASS-FORBS
      IF(IGFC(1).EQ.0) IGFC(1) = 9
      IF(IGFC(2).EQ.0) IGFC(2) = 9
      CODEX = (CODE(IGFC(1)) + CODE(IGFC(2)))/ 2.0
      PCV(3,IC) = PCV(3,IC) + YX*CODEX/4.0
      PCV(4,IC)=PCV(4,IC)+YY/4.0
C  *** CALCULATE BRUSH LOADINGS BY SIZE CLASS AND SPECIES
      TOTBW=0.0
      DO 520 I=1,10
C     * CHECK AND COMBINE SIMILAR SPECIES
      IF (ISP(I).EQ.4H    ) GO TO 520
      IF (ISP(I).EQ.4HVAME) ISP(I)=NSP(19)
      DO 480 K=1,28
      IF (ISP(I).EQ.NSP(K)) GO TO 500
  480 CONTINUE
      IY = IY + 1
      IDUM1(IY) = ISP(I)
      GO TO 520
C     * SPECIES IS UNIDENTIFIED.  CHECK FOR SMALL OR LARGE STEM
C     * CALCULATE SHRUB WEIGHT
  500 KK = K
      DO 510 J=1,7
      IF (NST(I,J).EQ.0) GO TO 510
      XX = REG(J,K) * FLOAT(NST(I,J))* 8.8185
      IF (XX.GT.0.0) XX=XX*TSLP
      SHWT(J,KK,IC)=SHWT(J,KK,IC)+XX
      IF (XX.LE.0.0) GO TO 510
      TOTBW=TOTBW+XX
  510 CONTINUE
  520 CONTINUE
C     * LOAD CASE 20:  DEAD BRUSH
```

```
      X(20)=TOTBW*PD
      * LOAD CASE 23:  LIVE BRUSH
      X(23)=TOTBW-X(20)
      * LOAD CASE 21:  TOTAL DEAD FUEL
      X(8) = X(13) + X(18)
      X(21) = X(7) + X(8) + X(19) + X(20)/2.0
      X(24) = 0.0
      X(25) = 0.0
      X(26) = 0.0
      DO 540 I=1,19
      DO 540 J=1,4
      IF(ISPY(J).NE.ISPX(I)) GO TO 540
      SDLH(I,IC) = SDLH(I,IC) + HSP(J)
      XDLH(I,IC)=XDLH(I,IC)+1.0
      NSDL(I,IC)=NSDL(I,IC)+NSTM(J)
      CALL SEEDL(I,HSP(J),NSTM(J)   )
540   CONTINUE
      X(27)=X(24)+X(25)+X(26)
      * LOAD CASE 28:  TOTAL FUEL LOAD
      X(28)=X(21)+X(22)+X(23)/2.0+X(27)
 *** SUM THE LOADINGS BY SIZE CLASS
      DO 530 I=1,28
      XX=X(I)
      XLDS(I,IC)=XLDS(I,IC)+XX
      XLD2(I,IC)=XLD2(I,IC)+XX*XX
530   CONTINUE
 *** ASPECT SLOPE AND ELEVATION
      DO 550 I=1,3
      TCOA(I,IC)=TCOA(I,IC)+TCOI(I)
      IF (I.GE.3) GO TO 550
      TCO2(I,IC)=TCO2(I,IC)+TCOI(I)*TCOI(I)
      IF (TCON(I,IC).GT.TCOI(I)) TCON(I,IC)=TCOI(I)
      IF (TCOX(I,IC).LT.TCOI(I)) TCOX(I,IC)=TCOI(I)
550   CONTINUE
      * UPDATE THE COUNTER
      XN(IC)=XN(IC)+1.0
      GO TO 180
 *** OK  SPIT OUT ALL THAT GARBAGE
580   CALL OUTPUT(NC,IBN,ISPX,NAME,IO)
      IBN = 0
      END FILE IO
      IF(KEY.EQ.1) GO TO 20
      IC1=IC1+20
      IF (IC1.GT.NPS) GO TO 20
      I2=IC1+19
      IF (I2.GT.NPS) I2=NPS
      NC=I2-IC1+1
      GO TO 170
      END

14-00       MAINPROG    .MAIN      03/04/82  15:27:44  TABLE SPACE:  11 KB
   20 LINES/1321 BYTES     STACK SPACE: 209 WORDS
FLOATING PT SUPPORT REQUIRED FOR EXECUTION
```

```
      SUBROUTINE OUTPUT(NC,IBN,ISPX,NAME,IO)
      CHARACTER NAME(2,28)*6,ICON*5
      DIMENSION ITO(4,28),ISPX(19)
      COMMON /HED/ IHEAD(15),ICLT(144),ICON(2),ILAST,KEY,XINC,NPS,IC1,
     1IPS(144),ICVT,IHBT,SAGE,IDUM1(100),IY
      COMMON XLDS(28,20),XLD2(28,20),DEP(12,20),PCV(4,20),XNDP(8,20),X(
     *28)
     1,ADIA(2,20),XND(2,20),DEP2(2,20),SHWT(7,28,20),XN(20),DMX(2,20),
     2XNLT(20),XNGF(20),DMN(2,20),NSDL(19,20),SDLH(19,20),XDLH(19,20),TC
     3OA(3,20),TCON(2,20),TCOX(2,20),TCO2(2,20),STCA(2,20),STCN(2,20),ST
     4CX(2,20),STC2(2,20)
      DATA ITO/4H    ,4H 0-.,4H25  ,4H    ,
     *4H    ,4H .25,4H-1  ,4H    ,4H    ,4H LIT,4HTER ,4H    ,
     *4HDEAD,4H HER,4HBS  ,4H    ,4H    ,4H FIN,4HES  ,4H    ,
     *4H    ,4H 1-3,4H    ,4H    ,4H  LE,4HSS T,4HHAN ,4H3   ,
     *4H3+  ,4HTOTA,4HL   ,4H    ,4H   S,4HOUND,4H 3-6,4H    ,
     *4H   S,4HOUND,4H 6-1,4H0   ,4H   S,4HOUND,4H 10-,4H20  ,
     *4H   S,4HOUND,4H 20+,4H    ,4H3+ S,4HOUND,4H TOT,4HAL  ,
     *4H   R,4HOTTE,4HN 3-,4H6   ,4H   R,4HOTTE,4HN 6-,4H10  ,
     *4H   R,4HOTTE,4HN 10,4H-20 ,4H   R,4HOTTE,4HN 20,4H+   ,
     *4H3+ R,4HOTTE,4HN TO,4HTAL ,4HDUFF,4H    ,4H    ,4H    ,
     *4HDEAD,4H SHR,4HUB  ,4H    ,4HDEAD,4HFUEL,4H LOA,4HD   ,
     *4HLIVE,4H HER,4HBS  ,4H    ,4H   L,4HIVE ,4HSHRU,4HB   ,
     *4HTREE,4H NEE,4HDLES,4H    ,4H    ,4H 0-.,4H25  ,4H    ,
     *4H    ,4H .25,4H + ,4H    ,4HTOTA,4HL TR,4HEE  ,4H    ,
     *4HTOTA,4HL LO,4HAD  ,4H    /
      DO 450 IC=1,NC
      IF (XN(IC).LE.0.0) GO TO 450
      XN2=XN(IC)*2.0
C *** PRINT OUT FUEL LOADING SUMMARY
C     * TITLE AND HEADING
      INP=XN(IC)
      CALL HEAD (IC,IO)
      WRITE (IO,10) INP
   10 FORMAT (/,23X,44H**********  FUEL LOADING SUMMARY  **********,/,3
     17X,'(FOR',I5,' PLOTS)',/26X,'I',4X,'LOADING IN OVEN-DRY POUNDS/ACR
     2E'5X,'I',11X,'I' / 13X,'SIZE CLASS   I  AVERAGE',15X,'STD-DEV  %ER
     3ROR I  KG/SQ-M  I')
      WRITE (IO,20)
   20 FORMAT (10X,16('-'),'I',40('-'),'I',11('-'),'I')
      DO 90 IL=1,28
C     * AVERAGE THE LOADINGS BY SIZE CLASS
      XX=XN(IC)
      IF (IL.EQ.20.OR.IL.EQ.23) XX=XN2
      IF (XX.LE.0.0.OR.XLDS(IL,IC).LE.0.0) GO TO 30
      XLDS(IL,IC)=XLDS(IL,IC)/XX
C     * STANDARD DEVIATION
      IF (XX.LE.1.0.OR.XLDS(IL,IC).LE.0.0) GO TO 40
      XLD2(IL,IC)=STDV(XLD2(IL,IC),XLDS(IL,IC),XX)
C     * PERCENT ERROR
      X(IL)=XLD2(IL,IC)/(SQRT(XX)*XLDS(IL,IC))*100.0
      GO TO 50
   30 XLDS(IL,IC)=0.0
   40 XLD2(IL,IC)=0.0
      X(IL)=0.0
   50 PPSF =(XLDS(IL,IC) / 43560.0)* 4.8824
      IF(IL.EQ.19) WRITE(IO,20)
```

```
   IF (IL.EQ.5.OR.IL.EQ.8.OR.IL.EQ.21.OR.IL.EQ.28) WRITE(IO,20)
   IF ((IL.GT.8.AND.IL.LT.18.AND.IL.NE.13).OR.(IL.LE.4).OR.((IL.GE.
  124).AND.(IL.LE.26))) GO TO 70
   IF(IL.EQ.6) GO TO 70
   IF(IL.EQ.20) GO TO 70
   IF(IL.EQ.22) GO TO 70
   IF(IL.EQ.23) GO TO 70
   IF(IL.EQ.19) GO TO 85
   * PRINT OUT FUEL LOADING
   WRITE(IO,60) (ITO(I,IL),I=1,4),XLDS(IL,IC),XLD2(IL,IC),X(IL),PPSF
 60 FORMAT(10X,4A4,'I',F10.0,11X,F10.0,F7.1,2X,'I',F10.3,' I')
   GO TO 90
 70 WRITE(IO,80) (ITO(I,IL),I=1,4),XLDS(IL,IC),XLD2(IL,IC),X(IL),PPSF
 80 FORMAT(10X,4A4,'I',10X,F10.0,1X,F10.0,F7.1,2X,'I',F10.3,' I')
   GO TO 90
 85 WRITE(IO,86) (ITO(I,IL),I=1,4),XLDS(IL,IC),PPSF
 86 FORMAT(10X,4A4,'I',10X,F10.0,20X,'I',F10.3,' I' )
 90 CONTINUE
*** AVERAGE FUEL DEPTHS
   * AVERAGE FUEL DEPTH
   DO 120 I=1,12
   XX=XN(IC)
   IF(I.EQ.2) XX = IBN
   IF (I.LT.3.OR.I.GT.10) GO TO 95
   J=I-2
   XX=XNDP(J,IC)
 95 IF (XX.LE.0.0) GO TO 110
   DEP(I,IC)=DEP(I,IC)/XX
   GO TO 120
.10 DEP(I,IC)=0.0
.20 CONTINUE
   * STANDARD DEVIATION
   DO 130 I=1,2
   XN3=XN2
   IF(I.EQ.2) XN3=IBN
   DEP2(I,IC) = STDV(DEP2(I,IC),DEP(I,IC),XN3)


.30 CONTINUE
   * PRINT OUT FUEL DEPTHS
   WRITE(IO,140)
 40 FORMAT(/,24X,42H**********    DEPTH (INCHES)    ***********       )
   WRITE (IO,150)
   WRITE (IO,160) (DEP(I,IC),DMN(I,IC),DMX(I,IC),DEP2(I,IC),I=1,2)
 50 FORMAT (31X,'I  AVERAGE  MINIMUM  MAXIMUM  STD-DEV I'/19X,12('-'
  1),'I',37('-'),'I')
 60 FORMAT(22X,'DUFF       I',4(F8.2,1X),' I' / 22X,'SHRUB    I',4(F8.2,
  11X)' I')
''' PRINT OUT TOPO CONDITIONS
   CALL HEAD (IC,IO)
   DO 200 I=1,3
   TCOA(I,IC)=TCOA(I,IC)/XN(IC)
   IF (I.GE.3) GO TO 200
   TCO2(I,IC)=STDV(TCO2(I,IC),TCOA(I,IC),XN(IC))
.00 CONTINUE
   WRITE (IO,210)
 10 FORMAT (//,22X,46H**********  TOPOGRAPHIC CONDITIONS  **********)
```

```
      WRITE (IO,150)
      WRITE (IO,220) TCOA(1,IC),TCON(1,IC),TCOX(1,IC),TCO2(1,IC)
  220 FORMAT(23X,'SLOPE    I',3(F8.1,1X),F8.2,'  I')
      WRITE (IO,230) TCOA(3,IC)
  230 FORMAT (23X,'ASPECT  I',F8.1,29X,'I')
      WRITE (IO,240) TCOA(2,IC),TCON(2,IC),TCOX(2,IC),TCO2(2,IC)
  240 FORMAT (21X,'ELEVATION I',3(F8.0,1X),F8.1,'  I')
      IF(IY.LE.0) GO TO 15
      IF(IY.GT.26) IY = 26
      WRITE(IO,575) (IDUM1(I),I=1,IY)
  575 FORMAT(                             /10X'THESE CODES D
     1POND TO THE LIST OF ACCEPTABLE BRUSH SPECIES.'/  10X,'THIS DATA WA
     3S NOT USED IN THE CALCULATIONS. ' / 10X,13(A4,1X) / 10X,13(A4,1X))
   15 CONTINUE
C  *** PRINT OUT THE BRUSH LOADING HEADING
      INP2=XN2
      WRITE (IO,330) INP2
      WRITE (IO,340)
C     * CALCULATE SHRUB LOADING BY SPECIES
      DO 250 J=9,16
      X(J)=0.0
  250 CONTINUE
      DO 300 I=1,28
      X(8)=0.0
      DO 280 J=1,7
      IF (SHWT(J,I,IC).EQ.0.0) GO TO 270
      IF (SHWT(J,I,IC).LT.0.0) GO TO 260
      X(J)=SHWT(J,I,IC)/XN2
      X(8)=X(8)+X(J)
      GO TO 280
  260 X(J)=SHWT(J,I,IC)
      X(8)=X(8)+1E-20
      GO TO 280
  270 X(J)=0.0
  280 CONTINUE
      IF (X(8).EQ.0.0) GO TO 300
C     * SUM HIGH, MEDIUM, LOW, AND UNDEFINED BRUSH
C     * WRITE OUT THE BRUSH WEIGHTS
      WRITE (IO,350) (NAME(K,I),K=1,2),(X(J),J=1,8)
      DO 290 J=1,8
      IF (X(J).LE.0.0) GO TO 290
      K=J+8
      X(K)=X(K)+X(J)
  290 CONTINUE
  300 CONTINUE
      WRITE (IO,340)
      WRITE (IO,360) (X(J),J=9,16)
  330 FORMAT (//,10X,7H*******,2X,'AVERAGE LIVE AND DEAD SHRUB LOADINGS
     1IN POUNDS/ACRE',2X,7H*******,/,31X,'(FOR',I5,' PLOTS)',/,21X,'I',1
     23X,'SIZE CLASS IN CENTIMETERS',12X,'I',/,8X,'SPECIES',6X,'I   0-.5
     3   .5-1  1-1.5  1.5-2    2-3    3-5     5+ I  TOTAL')
  340 FORMAT (8X,13('-'),'I',50('-'),'I',7('-'))
  350 FORMAT (8X,2A6,' I',7F7.1,' I',F7.1)
  360 FORMAT (8X,'TOTAL',8X,'I',7F7.1,' I',F7.1)
C  *** PERCENTAGE ESTIMATES AND 3+ SOUND XND ROTTEN
C     * AVERAGE PERCENT BRUSH COVER
      DO 370 I=1,4
```

```
      PCV(I,IC)=PCV(I,IC)/XN(IC)*100.0
  370 CONTINUE
      * AVERAGE DIAMETERS
      DO 390 I=1,2
      IF (XND(I,IC).LE.0.0) GO TO 380
      ADIA(I,IC)=ADIA(I,IC)/XND(I,IC)
      GO TO 390
  380 ADIA(I,IC)=0.0
  390 CONTINUE
      * PRINT OUT ESTIMATES
      X(1)=XLDS(13,IC)/2000.0*80.12
      X(2)=XLDS(18,IC)/2000.0*106.83
      WRITE (IO,400) (PCV(I,IC),I=1,4),(X(I),ADIA(I,IC),I=1,2)
  400 FORMAT (//,9X,71H*****  PERCENTAGE  ESTIMATES  *******  3+  VOLU
     1ME AND DIAMETER  ***** / 9X,'I      SHRUB       I      HERBS     I
     2     SOUND        I        ROTTEN       I',/,9X,'I',2(' %COVER  %DEAD  I'
     3),2('  CU-FT  AVG.DIA I'),/,9X,'I',2(16('-'),'I'),2(17('-'),'I'),/
     4,9X,'I',2(2(F6.1,2X),'I'),2(F7.0,F8.2,'  I'))
   *** SEEDLING COUNT
      WRITE (IO,410)
  410 FORMAT(// 23X,38H**********   SMALL  TREES   ********** / 28X,'SPE
     1CIES  TREES/ACRE  AVG.HT.FT.')
      TOTSED=0.0
      DO 430 I=1,19
      IF (NSDL(I,IC).EQ.0) GO TO 430
      SEED=FLOAT(NSDL(I,IC))*300.0/XN(IC)
      TOTSED=TOTSED+SEED
      AVHT=SDLH(I,IC)/XDLH(I,IC)
      WRITE (IO,420) ISPX(I),SEED,AVHT
  420 FORMAT (31X,A2,1X,F10.0,2X,F10.2)
  430 CONTINUE
      WRITE (IO,440) TOTSED
  440 FORMAT (29X,'TOTAL',F10.0)
  450 CONTINUE
      RETURN
      END

 R04-00      SUBROUTINE  OUTPUT    03/04/82  15:27:54  TABLE SPACE:   7 KB
 :,  20 LINES/1321 BYTES    STACK SPACE: 185 WORDS
  FLOATING PT SUPPORT REQUIRED FOR EXECUTION
```

```
      SUBROUTINE LOOK (I,D1,D2,D3)
C   *** SET MULTIPLICATION CONSTANTS BASED ON COVER
      IF (I.EQ.0) GO TO 140
      GO TO(30,140,140,140,30,140,30,140,140,40,20,140,140,10,30,140,40,
     1140,140,140),I
   10 D1=0.0342
      GO TO 50
   20 D1=0.0201
      GO TO 50
   30 D1=0.0122
      GO TO 50
   40 D1=0.0149
   50 GO TO(70,140,140,140,70,140,70,140,140,80,60,140,140,80,70,140,80,
     1140,140,140),I
   60 D2=0.344
      GO TO 90
   70 D2=0.304
      GO TO 90
   80 D2=0.238
   90 GO TO(100,140,140,140,110,140,110,140,140,120,110,140,140,100,110,
     1140,120,140,140,140),I
  100 D3=3.12
      GO TO 130
  110 D3=2.87
      GO TO 130
  120 D3=2.17
  130 RETURN
  140 D1=0.0151
      D2=0.289
      D3=2.76
      RETURN
      END
```

'D R04-00 SUBROUTINE LOOK 03/04/82 15:27:55 TABLE SPACE: 2 KB
'FER: 20 LINES/1321 BYTES STACK SPACE: 52 WORDS
;ION FLOATING PT SUPPORT REQUIRED FOR EXECUTION

```
      SUBROUTINE ZERO (NC)
C *** ZERO OUT ALL STORAGE ARRAYS
      COMMON XLDS(28,20),XLD2(28,20),DEP(12,20),PCV(4,20),XNDP(8,20),X(2
     18),ADIA(2,20),XND(2,20),DEP2(2,20),SHWT(7,28,20),XN(20),DMX(2,20),
     2XNLT(20),XNGF(20),DMN(2,20),NSDL(19,20),SDLH(19,20),XDLH(19,20),TC
     3OA(3,20),TCON(2,20),TCOX(2,20),TCO2(2,20),STCA(2,20),STCN(2,20),ST
     4CX(2,20),STC2(2,20)
      DO 80 IC=1,NC
      XN(IC)=0.0
      XNLT(IC)=0.0
       XNGF(IC)=0.0
      DO 10 J=1,28
      XLDS(J,IC) = 0.0
      XLD2(J,IC) = 0.0
   10 CONTINUE
      DO 20 J=1,12
      DEP(J,IC)=0.0
   20 CONTINUE
      DO 30 J=1,8
      XNDP(J,IC)=0.0
   30 CONTINUE
      DO 40 J=1,3
      TCOA(J,IC)=0.0
   40 CONTINUE
      DO 50 J=1,2
      DEP2(J,IC) = 0.0
      ADIA(J,IC) = 0.0
      XND(J,IC) = 0.0
      DMX(J,IC) = -1.0E+20
      STCX(J,IC) = -1.0E+20
      TCOX(J,IC) = -1.0E+20
      DMN(J,IC) = 1.0E+20
      STCN(J,IC) = 1.0E+20
      TCON(J,IC) = 1.0E+20
      STCA(J,IC) = 0.0
      STC2(J,IC) = 0.0
      TCO2(J,IC) = 0.0
   50 CONTINUE
      DO 60 I=1,28
      DO 60 J=1,7
      SHWT(J,I,IC)=0.0
   60 CONTINUE
      DO 70 J=1,4
      PCV(J,IC)=0.0
   70 CONTINUE
      DO 80 J=1,19
      SDLH(J,IC) = 0.0
      XDLH(J,IC) = 0.0
      NSDL(J,IC)=0
   80 CONTINUE
      RETURN
      END
```

```
04-00       SUBROUTINE  ZERO       03/04/82  15:27:57  TABLE SPACE:   3 KB
   20 LINES/1321 BYTES    STACK SPACE: 126 WORDS
FLOATING PT SUPPORT REQUIRED FOR EXECUTION
```

R04-00


```
      FUNCTION STDV (XX,XMN,XN)
      IF (XN.LE.1.0) GO TO 10
      STDV=SQRT((XX-XN*(XMN**2))/(XN-1.0))
      GO TO 20
   10 STDV=0.0
   20 RETURN
      END
```

```
'D  R04-00     FUNCTION    STDV      03/04/82  15:27:58  TABLE SPACE:   1 KB
'FER:   20 LINES/1321 BYTES    STACK SPACE: 151 WORDS
;ION FLOATING PT SUPPORT REQUIRED FOR EXECUTION
```

```
      SUBROUTINE HEAD (IC,IO)
      CHARACTER ICVTP*10,ICON*5
      DIMENSION ICVTP(2,12)
      COMMON/HED/ IHEAD(15),ICLT(144),ICON(2),ILAST,KEY,XINC,NPS,IC1,IP
     1S(144),ICVT,IHBT,SAGE,IDUM1(100),IY
      DATA ICVTP/  'PONDEROSA ',   'PINE       ',
     1             'LODGEPOLE ',   'PINE       ',
     2             'DOUGLAS-FI',   'R          ',
     3             'SPRUCE, SP',   'RUCE FIR   ',
     4             'ALPINE FIR',   '           ',
     5             'GRAND FIR ',   '           ',
     6             'WESTERN RE',   'D CEDER    ',
     7             'BRUSH     ',   '           ',
     8             'ALPINE LAR',   'CH         ',
     9             'WHITEBARK ',   'PINE       ',
     $             'GRASS     ',   '           ',
     $             'UNDEFINED ',   '           '   /
      DATA IPAGE/0/
      IPAGE=IPAGE+1
      IX=IC+IC1-1
 *** PRINT OUT TITLE
      WRITE(IO,10) (IHEAD(I),I=1,15),IPAGE
      IF(KEY.EQ.1) WRITE(IO,15) ICVT,IHBT,SAGE
   10 FORMAT(1H1,9X,15A4,'  PAGE ',I3 /)
   15 FORMAT(                        10X,'COVER TYPE  ',A3,2X,'HABITA
     1T TYPE ',I3,2X,'STAND AGE ',F4.0 )
      GO TO(40,150,170),KEY
      * STANDS SEPERATELY
   40 WRITE (IO,50) ILAST
   50 FORMAT(36X,'STAND NUMBER ',I4)
      GO TO 210
      * COVER TYPE CODES
  150 I1=ICLT(IX)
      WRITE (IO,160) (ICVTP(I,I1),I=1,2)
  160 FORMAT (30X,'COVER TYPE  ',2A10)
      GO TO 210
      * HABITAT TYPE CODE
  170 WRITE (IO,180) ICLT(IX)
  180 FORMAT (34X,'HABITAT TYPE CODE',I4)
  210 RETURN
      END
```

04-00 SUBROUTINE HEAD 03/04/82 15:27:59 TABLE SPACE: 2 KB
20 LINES/1321 BYTES STACK SPACE: 122 WORDS

```
      SUBROUTINE SEEDL(ISP,XHT,NUM)
      DIMENSION Z1(3,19) , Z2(3,19) , Z(3)
      COMMON XLDS(28,20),XLD2(28,20),DEP(12,20),PCV(4,20),XNDP(8,20),X(2
     18),ADIA(2,20),XND(2,20),DEP2(2,20),SHWT(7,26,20),XN(20),DMX(2,20),
     2XNLT(20),XNGF(20),DMN(2,20),NSDL(19,20),SDLH(19,20),XDLH(19,20),TC
     3OA(3,20),TCON(2,20),TCOX(2,20),TCO2(2,20),STCA(2,20),STCN(2,20),ST
     4CX(2,20),STC2(2,20)
      DATA Z1/.51,.21,.28,
     *        .0 ,.0 ,.0 ,
     *        .0 ,.0 ,.0 ,
     *        .0 ,.0 ,.0 ,
     *        .51,.21,.28,
     *        .0 ,.0 ,.0 ,
     *        .38,.18,.44,
     *        .51,.21,.28,
     *        .0 ,.0 ,.0 ,
     *        .26,.23,.51,
     *        .38,.18,.44,
     *        .38,.18,.44,
     *        .0 ,.0 ,.0 ,
     *        .38,.18,.44,
     *        .51,.21,.28,
     *        .38,.18,.44,
     *        .26,.23,.51,
     *        .48,.21,.31,
     *        .0 ,.0 ,.0 /
      DATA Z2/.40,.16,.44,
     *        .0 ,.0 ,.0 ,
     *        .0 ,.0 ,.0 ,
     *        .C ,.0 ,.0 ,
     *        .40,.16,.44,
     *        .0 ,.0 ,.0 ,
     *        .31,.14,.55,
     *        .40,.16,.44,
     *        .0 ,.0 ,.0 ,
     *        .21,.19,.60,
     *        .31,.14,.55,
     *        .31,.14,.55,
     *        .0 ,.0 ,.0 ,
     *        .31,.14,.55,
     *        .40,.16,.44,
     *        .31,.14,.55,
     *        .21,.19,.60,
     *        .31,.16,.53,
     *        .0 ,.0 ,.0 /
      YN=NUM*300.
      GO TO (110,199,199,199,80,199,100,70,80,90,60,20,199,50,10,20,
     140,30,70) ISP
   10 CW=YN*.019604*XHT**2.571
      GO TO 200
   20 CW=YN*.005940*XHT**2.563


      GO TO 200
   30 CW=YN*.3292*XHT
      GO TO 200
   40 CW=YN*.070+.02446*XHT**2.0
```

```
      GO TO 200
  50  CW=YN*.3451*XHT
      GO TO 200
  60  CW=YN*.03111*XHT**2.0
      GO TO 200
  70  CW=YN*.4284*XHT
      GO TO 200
  80  CW=YN*.04833*XHT**2.0
      GO TO 200
  90  CW=YN*.1128*XHT+.00813*XHT**2
      GO TO 200
 100  CW=YN*.01482*XHT**2.7168
      GO TO 200
 110  CW=YN*.035615*XHT**2.303
      GO TO 200
 199  RETURN
 200  DO 210 I= 1,3
      IF(XHT.LE.4.9) Z(I) = Z1(I,ISP)
      IF(XHT.GE.5.0) Z(I) = Z2(I,ISP)
 210  CONTINUE
      X(24) = X(24) + CW * Z(1)
      X(25) = X(25) + CW * Z(2)
      X(26) = X(26) + CW * Z(3)
      RETURN
      END

04-00      SUBROUTINE  SEEDL      03/04/82  15:28:02  TABLE SPACE:    4 KB
    20 LINES/1321 BYTES     STACK SPACE: 144 WORDS
FLOATING PT SUPPORT REQUIRED FOR EXECUTION
```

APPENDIX IV
FIELDWORK HINTS

1. Steep slopes and heavy brush will slow procedures from 5 to 10 minutes per sample point. Keep this in mind when laying out the day's work.
2. In bogs or moist areas, it can be difficult to distinguish the division between duff and mineral soil. It may be desirable to establish a lower limit such as 12 inches. Below this, duff should not be measured.
3. Before going to the field, label bags for collecting herbs and litter.
4. Keep herb and litter samples in porous containers to prevent mildew. If the weather permits, hang samples where they can air-dry.
5. Approach sample point centers cautiously to avoid disturbing vegetation. At each point, lay out the sampling plane and subplots before doing any sampling. This will minimize disturbance of vegetation to be sampled.
6. In areas with abundant herbaceous vegetation, take larger bags for collecting samples.
7. Fill out the forms in pencil with dark lead. Mistakes can be easily erased.
8. Take care to enter data and label sacks clearly. Make sure all the recording is completed in the field at each plot while it is still fresh in your mind.

☆ U.S. GOVERNMENT PRINTING OFFICE: 1982—576-026/15 REGION No. 8

Brown, James K., Rick D. Oberheu, and Cameron M. Johnston. 1981. Handbook for inventorying surface fuels and biomass in the Interior West. USDA For. Serv. Gen. Tech. Rep. INT-129, 48 p. Intermt. For. and Range Exp. Stn., Ogden, Utah 84001.

Presents comprehensive procedures for inventorying weight per unit area of living and dead surface vegetation, to facilitate estimation of biomass and appraisal of fuels. Provides instructions for conducting fieldwork and calculating estimates of downed woody material, forest floor litter and duff, herbaceous vegetation, shrubs, and small conifers. Procedures produce the most accurate estimates in the Interior West; however, techniques for herbs, litter, and downed woody material are applicable anywhere. Includes computer program and card punching instructions for processing inventory data.

KEYWORDS: sampling, forest floor estimation, shrub estimation, grass and forb estimation, forest fuel estimation

The Intermountain Station, headquarted in Ogden, Utah, is one of eight regional experiment stations charged with providing scientific knowledge to help resource managers meet human needs and protect forest and range ecosystems.

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United States
Department of
Agriculture

Forest Service

**Intermountain
Forest and Range
Experiment Station
Ogden, UT 84401**

General Technical
Report INT-130

August 1982

Seventy Years of Vegetative Change in a Managed Ponderosa Pine Forest in Western Montana—Implications for Resource Management

George E. Gruell, Wyman C. Schmidt,
Stephen F. Arno, and William J. Reich

THE AUTHORS

GEORGE E. GRUELL is a research wildlife biologist with the Fire Effects and Use research work unit, Northern Forest Fire Laboratory, Missoula, Mont. Gruell's research has been primarily in the area of plant succession, fire, and wildlife habitat condition.

WYMAN C. SCHMIDT is a research silviculturist and project leader of the Silviculture of Northern Rocky Mountain Subalpine Forest Ecosystems research work unit at the Forestry Sciences Laboratory, Bozeman, Mont. Dr. Schmidt's research has focused primarily on the ecology, stand development, and silviculture of young coniferous forests of the Intermountain and Northern Rocky Mountain West.

STEPHEN F. ARNO is a plant ecologist on the Fire Effects and Use research work unit at Missoula, Mont. He has studied various aspects of forest ecology including succession and fire history.

WILLIAM J. REICH is a 1978 graduate of the University of Montana School of Forestry. He was a temporary employee with the Fire Effects and Use research work unit during 1979 and 1980.

CONTENTS

RESEARCH SUMMARY

This paper documents successional changes in a ponderosa pine forest in the Bitterroot Valley of western Montana. The area described comprises the Lick Creek timber sale of 1906, the first large ponderosa pine sale in the USDA Forest Service Northern Region. The timber volumes, cutting methods, volume removed, and subsequent management are discussed. Prior to cutting, frequent low-intensity surface fires were a major influence on the vegetation of Lick Creek. Consequently, fire history is treated in some detail.

A series of 11 photopoints, photographed at about 10-year intervals starting in 1909, provide a basis for interpretations. The photographs show dramatic changes in vegetation as a result of disturbance from timber harvest and virtual exclusion of wildfire. The forest structure was originally dominated by mature ponderosa pine with an open understory. This structure was converted to widely spaced mature pines interspersed within dense second-growth mixed ponderosa pine/Douglas-fir forests. Subsequent reentries opened these stands and allowed increased establishment and growth of conifers and shrubs. Implications for management resulting from forestry practices are as follows:

1. Repeated timber harvests at Lick Creek have demonstrated that it is possible to partially cut old-growth ponderosa pine-dominated stands and obtain ample regeneration. Growth release on residual mature trees has been modest, but release in thinned second-growth stands has been substantial.
2. The cutting program coupled with fire suppression over the past 70 years has favored regeneration of Douglas-fir over ponderosa pine on much of the area. A dense understory of trees developed in response to partial cuttings.
3. The increase in understory tree cover and shrubs has changed wildlife habitat. Species that require dense cover, such as white-tailed deer and snowshoe hare, have been favored. Species that require minimal cover, like ground squirrels and pocket gophers, would not be favored.
4. Present conifer stands are more susceptible to crown fires than the early stands because of the increase in ladder fuels. Down and dead fuels have continued to be light except for slash created by precommercial thinning.
5. In the decades following initial logging, scenic quality has deteriorated because dense conifer regeneration has obstructed views.
6. After about 1912, livestock grazing on the Lick Creek sale area apparently has been light and therefore has influenced vegetative development very little.

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May 1981

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ITRODUCTION

More than 100 years have passed since the initial ttlement of western Montana. During this period forest getation has changed, but there is little documentation the degree of changes, what brought about these anges, and the effect of these changes on forest sources and activities. This paper contains a photo-aphic record and supporting evidence of successional anges in a ponderosa pine/Douglas-fir forest typical of estern Montana. This area and comparable lands were gged (mostly partial cuts) starting as early as the 1880's. gging, grazing, and fire suppression resulted in succes-onal changes that differed from those that occurred in e presettlement environment. The implications of forest ccession on timber management, wildlife habitat, live-ock grazing, forest fuels, and scenic quality are dis-ssed. Content should prove useful to silviculturists, resters, fire management officers, wildlife biologists, d others who have management responsibilities. This formation should also be useful in furthering ecologi-lly sound forest management.

HE SETTING AND HISTORICAL ACKGROUND

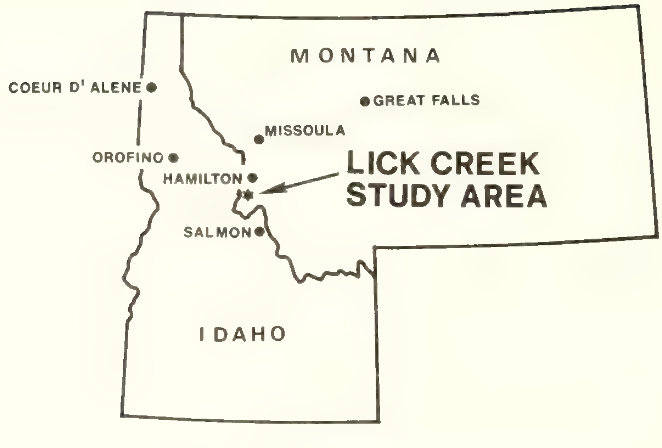
For much of forested North America, there is little iable information on changes in vegetation over long riods of time. An exception is the Lick Creek drainage the Bitterroot National Forest in Montana, thanks to e foresight of USDA Forest Service personnel who have otographically recorded vegetation over the past 70 ars. This photographic series provides a unique oppor-nity to visually interpret changes in a ponderosa pine/ uglas-fir forest (see appendix for common and scien-c names of trees and undergrowth). Changes depicted also allow an evaluation of how resource uses and activities have been influenced by logging and exclusion of wildfire. Similar changes have occurred over much of the ponderosa pine/Douglas-fir type in western Montana, where shade-tolerant Douglas-fir represents the potential climax were it not for disturbances like fire and logging.

The photo study is located on Lick Creek (lat. 46°5' N., long. 114°15' W.), site of a 1906 ponderosa pine timber sale on National Forest lands. This area is 13 airline miles (21 km) southwest of Hamilton, Mont., at elevations between 4,300 and 4,600 ft (1 311 and 1 402 m) (fig. 1). The terrain in this locality is mostly 10 to 30 percent slopes except for localized northerly and southerly slopes of up to 70 percent. Soils are derived from granitic parent materials and are shallow to moderately deep. Some poorly drained areas and clay soils exist at the lowest elevations.

Weather data recorded between 1941 and 1970 at Darby (elev. 3,887 ft [1 185 m]), Mont., 5 airline miles (8 km) southeast of the study area, suggest that the mean annual precipitation at Lick Creek is between 20 and 22 inches (51 and 56 cm) (USDA Soil Conservation Service 1977). Approximately 50 percent of this falls in the form of snow.

Because many years have passed since the original timber sale, records concerning USDA Forest Service participants are sketchy. Some of the people who are known to have been involved included Bitterroot Forest Supervisor, W. W. White, who administered the sale; John Preston, acting deputy forest supervisor; Earl Tanner; E. C. Clifford; Claget Sanders, the scaler; and "lumberman" C. J. Gregory. Although no documentation has been found, there is evidence that Gifford Pinchot, the first Chief of the USDA Forest Service, provided direction for this sale (personal communication, Arthur Roe, Forest

VICINITY MAP



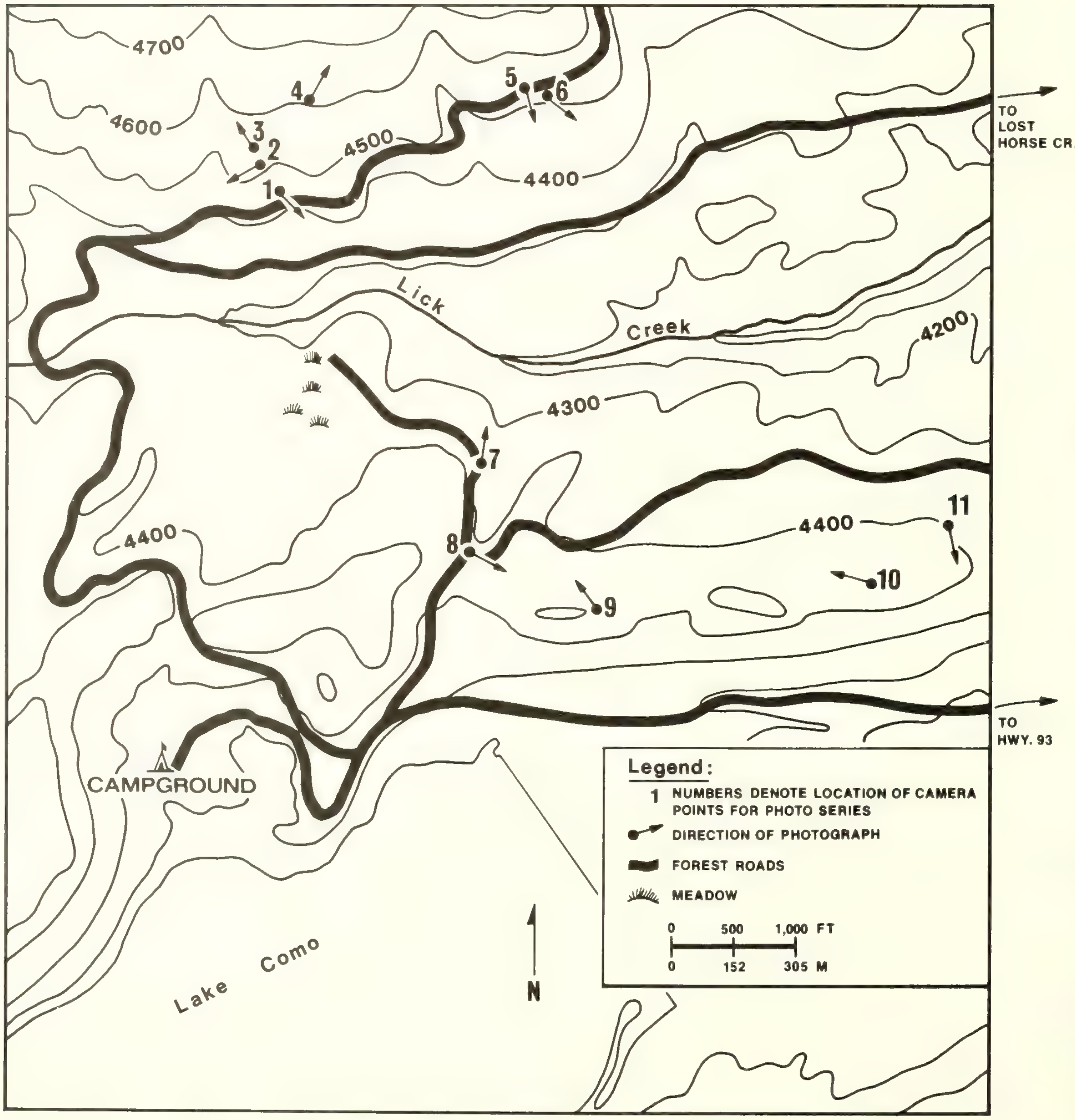


Figure 1.—Lick Creek study area.

ervice retired, and Charles Wellner, Forest Service tired). The Big Blackfoot Milling Company, a subsidiary the Anaconda Copper Mining Company, purchased the nber and did the logging according to USDA Forest ervice specifications.

Because of the importance of the Lick Creek sale, in 909 a Washington Office photographer, W. J. Lubkin, as sent West to document the logging activity. Lubkin otained excellent photos by using a 6½- by 8½-inch 7-by 22-cm) view box camera and glass plates.

The camera points were not permanently marked ecause this was not part of the assignment. Fortunately, November 1925, K. D. Swan, photographer for the USDA orest Service Northern Region, accompanied W. W. hite on a trip to the Lick Creek area to see if the mera points could be located. Swan (1968) recalled how hite was able to locate the original photo points:

> The quest was extremely fascinating. White had a good memory and was able to spot, in a general way, the locations we were after. Peculiar stumps and logs were a great help. Just when we might seem baffled in the search for a particular spot, something would show up to give us a key. The clue might be the bark pattern on a ponderosa pine, or perhaps a forked trunk.
>
> The camera we were using duplicated the one used for the original pictures, and when a spot was once found it was a simple matter to adjust the outfit so that the image on the ground glass would coincide with the print we were holding. It was an exciting game, and we felt it was more fun than work.

In 1938, the temporary camera points located in 1925 ere permanently marked with brass caps by Forest upervisor G. M. Brandborg and Ranger C. Shockley. The iginal photographs were repeated in 1925, 1927, and 37 by K. D. Swan. He was followed by three other USDA orest Service employees: W. E. Steuerwald, 1949, 1958; yman Schmidt, 1969; and William Reich, 1979. Most of e retake photographs were made with 4- by 5-inch (10- by -cm) Crown Graphic cameras.

LVICULTURAL STORY

The Lick Creek timber sale of 1906 attracted much tention because it was the first large national forest nber sale (2,135 acres [864 ha]) in the ponderosa pine pe in the USDA Forest Service Northern Region. A total 37,600,000 bd.ft. was cut.

Professional forestry and the USDA Forest Service were their infancy in the United States at that time, and ere was little research or experience on which to base vicultural prescriptions in any of our forest types. nderosa pine was, and continues to be, a high-value nber species.

Frequent light ground fires had favored ponderosa pine d had suppressed its more shade-tolerant associate in s type—Douglas-fir. Douglas-fir was economically less sirable than ponderosa pine, so silvicultural practices re aimed at perpetuating pine and reducing the fir component. Autecological requirements of all species were just beginning to be understood. Therefore silvicultural treatments were based on limited knowledge.

Harvest Cutting Treatments, 1907-11

The virgin stand was composed chiefly of mature and overmature ponderosa pine. Douglas-fir of inferior quality comprised about 10 percent of the stand volume. A small amount of grand fir and spruce was included in the Douglas-fir volume. Total volume of sawtimber (10 inches [25.4 cm] d.b.h. and larger) of all species averaged 20,810 bd.ft. per acre. Timber age ranged from 200 to 400 years, and based on Meyer's yield tables (1938), the site was originally classified as IV and V (about 39 to 50 ft [12 to 15 m] tall at 50 years). Subsequent evaluations indicate that these sites are actually more productive than that, with potential site indexes for uncrowded trees averaging about 52 to 55 ft (16 to 17 m) tall at 50 years for ponderosa pine and Douglas-fir (Pfister and others 1977; personal communication, B. John Losensky, USDA Forest Service Northern Region, Missoula, Mont.).

Although original descriptions of the Lick Creek cuttings did not classify the silvicultural system, it can best be described as a selective cutting. Timber marking practices in this early cutting followed these criteria:

1. Leave reserve timber for a second cut after 75 years.
2. As a general guide, reserve about 30 percent of the volume.
3. Cut Douglas-fir heavily (generally inferior quality).

Actual marking practices varied considerably during the 1907-11 period. A limited area was cut to a 19-inch (48-cm) diameter limit (everything over 19 inches [48 cm] was cut). The original stand contained an average of about 50 trees per acre (124/ha). Of these, an average of 25 per acre (62/ha) were cut in the 1907-11 period. Because most of the trees harvested were the larger trees, basal area remaining after logging averaged only about 37 percent of the original 121 ft^2 per acre (27 m^2/ha). Size class distribution of the residual stand after cutting was:

Size Class		Number Trees Per	
Inches	*cm*	*Acre*	*Hectare*
6 to 8	15 to 20	2	5
10 to 12	25 to 30	6	15
14 to 16	36 to 41	6	15
18 to 20	46 to 51	5	12
22 to 24	56 to 61	3	7
26 to 30	66 to 76	2	5
32 +	81 +	1	2

Residual basal areas and volumes, however, varied greatly on the cutover area, ranging from about 5 to 50 percent of the original stand (Boe 1948).

Actual cutting took place during the 1907-11 period, covering 2,135 acres (864 ha), 1,916 acres (776 ha) of which were classified as pine type, and 219 acres (88 ha) of which were classified as Douglas-fir and spruce. Grand fir was included in the latter. (Most of the area and all of the photopoints are within Douglas-fir habitat types [Pfister and others 1977].) A grand fir habitat type including some spruce occurs in moist sites along Lick Creek.

RESIDUAL STAND GROWTH RESPONSE

An evaluation of the Lick Creek area 35 years after the 1907-11 cuttings showed that average stand volume of trees 10 inches (25 cm) d.b.h. and larger had increased from 3,810 bd.ft. per acre (9 411/ha) in the residual stand in 1911 to 6,127 per acre (15 134/ha) in 1946 (Roe 1947a). This amounted to 66 bd.ft. per acre (163/ha) annual net growth. Fortunately, the residual stands that made up this average varied substantially and provided a basis to evaluate the effect of residual volume capital on subsequent growth.

To make these evaluations, Roe (1947a) grouped the 1911 residual volumes into four broad classes averaging 627 residual bd.ft. per acre (1 549/ha), 2,396 per acre (5 918/ha), 4,655 per acre (11 498/ha), and 9,089 per acre (22 450/ha).

Largest net volume increments were made in the heaviest residual stands. As shown in figure 2, average annual increment ranged from 2 bd.ft. per acre (4.9/ha) where the reserve stand had averaged 627 bd.ft. per acre (1 549/ha), to 126 bd.ft. per acre (311/ha) where the reserve stand had averaged 9,028 bd.ft. per acre (22 299/ha). Most growth was made by merchantable-size trees reserved at the time of the initial logging.

Although the greatest per acre gains were in stands with heaviest residual volumes, on a percentage basis, the most significant increases were in stands averaging 4,655 bd.ft. per acre (11 498/ha) (fig. 3) (Roe 1947b).

In the stands with light residual volume, Douglas-fir contributed most to the ingrowth (trees less than 10 inches [25 cm] d.b.h. at the time of the initial harvest that exceeded 10 inches [25 cm] d.b.h. at the 35-year measurement). The opposite was true in the stands with heavy residuals after the initial cutting. Here, nearly all of the 35-year growth was in ponderosa pine 10 inches (25 cm) d.b.h. and larger at the time of the initial cutting. Intermediate reserve stand volumes resulted in intermediate response values in relation to both species composition and volume growth. Thus, stand volume capital played a role in evaluating the efficacy of reserving different levels of stand volume.

White (1924)[1] described effects of release on individual ponderosa pine trees. He concluded that: "It was noticed that the removal of one or more trees on the north seemed to have as much effect on increased growth as where the removal was on the south. This was so pronounced that the conclusion is reached that root competition in yellow pine stands is fully as important a factor as light."

Volume increment in stands with the heaviest residual volume increased rapidly, peaked the second 5-year period after logging, remained relatively high for about 20 years, and then gradually declined (Roe 1947b). In stands with lighter residual volumes, the same trends were observed, except that ingrowth and apparent increased precipitation in the 30- to 35-year period after logging, resulted in increased growth.

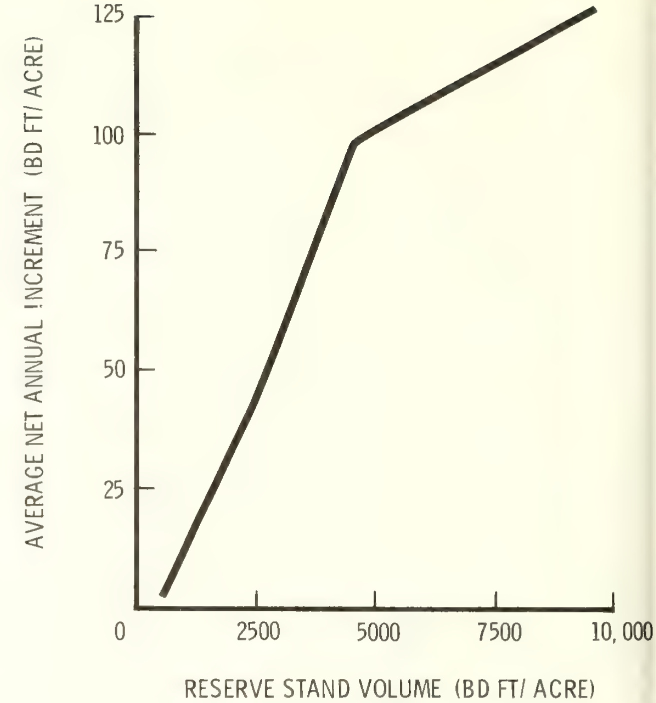


Figure 2.—Average annual net volume increment for 35 years following harvest cutting in relation to reserve stand volume.

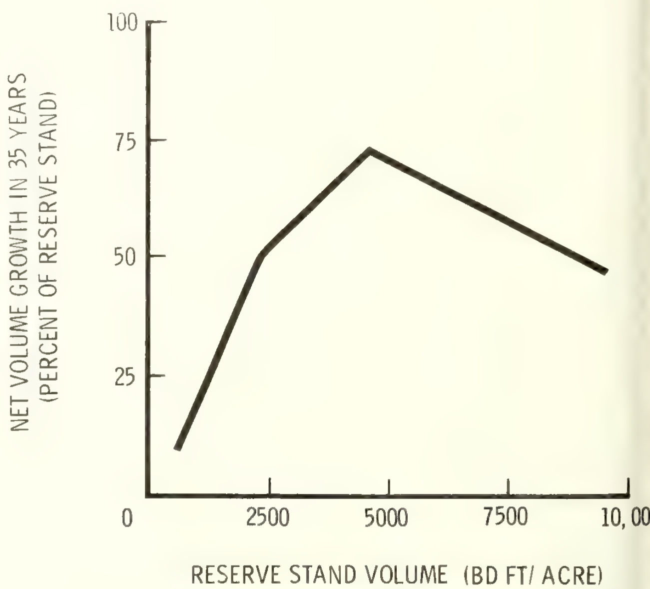


Figure 3.—Thirty-five year net volume growth as a percent of the reserve stand.

Ingrowth played a relatively small part over all of the cutover area because there were few understory trees, seedlings, saplings, and poles in 1907. Frequent ground fires precluded survival of most understory trees before that time.

The reserve stand was apparently chosen with a good appreciation of tree vigor. Mortality averaged only 8 to 18 bd.ft. per acre (20 to 44/ha) annually for the 35-year perioc No relationship of mortality rates to residual stand volume was detected. White (1924),[1] concluded that most

[1]White, W. W. Study of Lick Creek timber sale area 15 years after cutting. Hamilton, MT: U.S. Department of Agriculture, Forest Service, Bitterroot National Forest; April 28, 1924. 16 p. Office report.

nortality was due to windfall shortly after the cuttings, out a small amount was due to bark beetles. Ninety percent of the wind losses occurred the first 3 years after cutting. Windfall was worst on the east and southeast sides of large openings created by the logging. West and northwest winds were responsible for the wind losses.

NATURAL REGENERATION RESPONSE TO INITIAL TREATMENTS

During the 1907-11 harvest, logs were transported to landings by means of log chutes, horse skidding, and steam donkey yarding. Slash was disposed of by piling and burning. Usually this type of logging and postlogging treatment results in relatively light site disturbance, and the photo series tends to corroborate this. Some advance natural regeneration, primarily Douglas-fir, was present in the stand prior to logging; most of it became established in the 10-year period prior to logging (Boe 1948). However, opening of the stand, site disturbance of the logging, and apparent good seed crops resulted in adequate subsequent regeneration. White (1924)[1] stated: "Along about 1912, there was a heavy yellow pine seed crop. That fall, in October, the area was grazed close by sheep." The most successful regeneration period was the first 10 years after logging, with a gradual decline in the second and third decades.

Total subsequent regeneration combining all species was best where reserve volumes averaged about 2,500 bd.ft. per acre (6 175/ha). Lighter volumes resulted in lesser amounts of regeneration. Reserve volumes greater than 2,500 bd.ft. contributed little or no additional aid in seedling establishment except on southerly aspects where it enhanced Douglas-fir establishment. Apparently, reserve volumes of about 2,500 bd.ft. provided reasonably good conditions for all species, with an adequate seed source, and shade and moderate competition during the establishment period.

Some conclusions that came out of the evaluations of natural regeneration were (Boe 1948):

1. Douglas-fir reproduction tends to become established in advance of cutting, due to greater shade tolerance. The tendency is more pronounced on the cooler, moister north aspects where Douglas-fir predominates. Ponderosa pine generally regenerates after logging and predominates on the south slopes.
2. It took about 20 years after cutting to restock the area; however, the peak establishment occurred in the first 10 years.
3. Height growth of young ponderosa pine and Douglas-fir was about equal for the first 40 years, each averaging slightly more than 0.6 ft (19 cm) annually. Consequently, if both species become established at the same time, the danger of Douglas-fir crowding out the pine is greatly decreased.

Harvest Cutting Treatments, 1952-Present

Growth evaluations 35 years after the initial cuttings indicated that a second cutting was needed to better capitalize on growth potential of the site. So in the fifties, additional cuttings were made on a limited portion of the original cutover area. The following cutting methods were imposed on 468 acres (189 ha) within the original 1907-11 cutover area:

Method A

Remove old stand in four cuttings; the first in 1907-11, and the other three at 10-year intervals starting in 1952.

Method B

Remove old stand in three cuttings; the first in 1907-11, half the old residual in 1955, and the other half in 1962.

Method C

Remove old stand in two cuttings; the first in 1907-11, and the remainder of the residual stand in 1955.

At the time of the second cutting in the fifties, stand volumes averaged about 10,000 bd.ft. per acre (24 700/ha). Method A removed about one-fourth, Method B about one-half, and Method C about two-thirds of the total merchantable volume (10 inches [25 cm] d.b.h. and over) in the 1952 and 1955 cuttings. Logs were mainly tractor skidded, with a pan under the front of the logs; however, there was some supplemental jammer skidding.

Marking practices to accomplish these partial cuttings were:

1. Remove high-risk trees (those which would not survive 10 to 20 years).
2. Cut spike-topped and lightning-damaged trees.
3. Remove poor-quality subordinates of merchantable size, and poor-quality, rough dominants in mature and overmature groups.
4. Release high-quality subordinates by removing rough dominants in young bull pine groups.
5. Harvest extremely slow-growing, overmature trees.
6. Cut all merchantable Douglas-fir (lower merchantable diameter limit was 14 inches [36 cm] d.b.h.).
7. Remove all trees with visible butt rot or those leaning more than 20 degrees.

RESPONSE TO HARVEST CUTTINGS

Response following the fifties cuttings was similar to that after the original 1907-11 cuttings; greatest increases in merchantable volume were in stands with the largest reserve volumes. Net volume growth following the fifties harvest cuttings exceeded that after the original cuttings, ranging from about 150 bd.ft. per acre (370/ha) annual increment in stands with 2,000 bd.ft. reserve stand per acre (4 940/ha) to 235 bd.ft. (580/ha) in stands with 12,000 bd.ft. (29 640/ha) reserve stand volume. Ingrowth accounted for about 30 percent of the volume growth in the lightly stocked reserve stand and only about 3 percent in the more heavily stocked reserve stand. About half of the ingrowth was Douglas-fir in spite of the attempts to enhance ponderosa pine and discourage Douglas-fir.

Unfortunately, there was no evaluation of total cubic foot volume, which would have provided a better basis for evaluating the different treatments. Also, only one measurement was made 5 years after treatment.

Lumber recovered from these second cuttings was similar in quality to that from virgin stands. Approximately 15 percent of the lumber was select, 60 percent in two and three common grades, and the remainder in lower grades.

Immature Stand Culture

Culture of immature stands was started in the fifties on the Lick Creek study area. More than 5,000 ponderosa pine crop trees (100 per acre [247/ha]) were released and pruned on the area cut with method A of the 1952 partial cutting. Trees were 4 to 9 inches (10 to 23 cm) d.b.h. at the time. Release was provided by removing competitors in a 3- to 6-ft (1- to 2-m) radius around the crown of each crop tree. To increase quality of the featured ponderosa pine crop trees, each was pruned to at least 17 ft (5 m). Cost of release and pruning at that time was about $0.50 per crop tree, broken down into $0.25 for pruning, $0.16 for release, and $0.09 for supervision, supplies, and transportation costs.

Five-year evaluations of various intensities of pruning ponderosa pine showed a considerable reduction in d.b.h. growth on the severely pruned trees, with proportionately less reduction on the lightly pruned (fig. 4). Height growth was not affected.

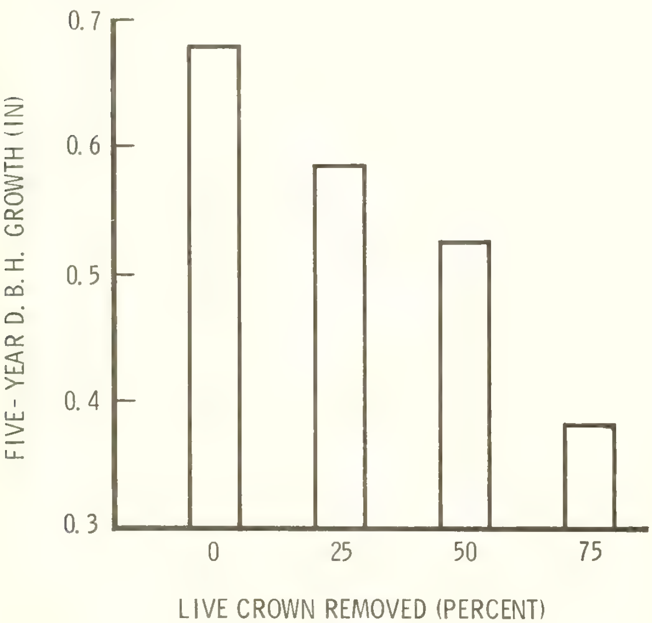


Figure 4.—Five-year diameter of 4- to 9-inch d.b.h. ponderosa pine crop trees following release as related to amount of crown pruning.

Cone stimulation studies were also conducted on this area. These studies showed that partial mechanical girdling of young ponderosa pine (50 years) would substantially increase cone production (Shearer and Schmidt 1970). Older trees (140 and 220 years), however, showed little additional cone production as a result of girdling treatments.

Summary

In summary, a variety of silvicultural practices have been attempted on the Lick Creek area. The long case histories and observational data of partial cutting, release, pruning, and cone stimulation practices provide valuable clues for management of this important forest type.

NATURAL FOREST SUCCESSION

"Succession" is the term applied to a change or sequence of vegetation on a given site through time. Fo example, a succession of plant communities that follow clearcutting with broadcast burning of slash might be: (grass-forb, (2) shrubfield, (3) saplings and shrubs, (4) pol size trees, (5) mature forest, and (6) old-growth forest. Succession also applies to the sequence of species tha dominate a general community type. Thus, a forest stan may initially be dominated by ponderosa pine (a shade-intolerant tree), which gives way to Douglas-fir (mid-tolerant), and finally to grand fir (shade-tolerant) with increasing time since disturbance. Modern forest managers need to be able to understand and predict succession because vegetation change greatly affects manage ment for grazing, wildlife, timber, watershed, and recrea tional values.

The Lick Creek photopoints present a rare opportunit to witness forest succession in managed stands throug 70 years of time. But in order to assess this manageme influenced succession, we should be aware of the kind forest succession that preceded it. The photopoints occ on two general types of sites or "habitat types," which support somewhat different vegetation and have differe patterns of succession (Pfister and others 1977). A habit type is a measure of site (physical environment) based upon the potential climax vegetation—the type of plant community that represents the self-perpetuating "end-point" of succession.

Fire and other disturbances usually prevent development of climax communities in these forests, but a kno edge of shade tolerances and successional trends allo us to identify the theoretical or potential climax on mos sites. This ultimate vegetative type is a reflection of the overall physical environment.

All of the Lick Creek photopoints occur on sites whe Douglas-fir (*Pseudotsuga*) is the potential climax dominant tree. The majority of points are located on tw relatively dry Douglas-fir habitat types:

1. *Pseudotsuga menziesii/Calamagrostis rubescens* h.t., *Pinus ponderosa* phase (PSME/CARU-PIPO; Douglas-fir/pinegrass h.t., ponderosa pine phase); and
2. *Pseudotsuga menziesii/Symphoricarpos albus* h.t., *Calamagrostis rubescens* phase (PSME/SYAL-CARU; Douglas-fir/snowberry h.t., pinegrass phase).

However, two photopoints are on moist Douglas-fir habitat types:

1. *Pseudotsuga menziesii/Vaccinium globulare* h.t., *Arctostaphylos uva-ursi* phase (PSME/VAGL-ARUV; Douglas-fir/blue huckleberry h.t., kinnikinnick phase); ar
2. *Pseudotsuga menziesii/Vaccinium caespitosum* h. (PSME/VACA; Douglas-fir/dwarf huckleberry h.t.).

It is evident from the early photographs, accounts of early forest conditions (Leiberg 1899), and fire history studies (Arno 1976), that prior to logging and the adven of fire suppression (about 1910), the lower elevation fores of the Bitterroot Valley were made up of well-stocked stands of large ponderosa pine having open understori Surface fires swept through these stands at intervals c between 3 and 30 years (Arno 1976), killing most of the tree regeneration, but causing little damage to oversto

trees except for fire scars at the base of the trunk (Leiberg 1899). These fires killed the aerial portions of grasses and shrubs, but afterwards most of these species regenerated from underground organs.

Lightning was a principal cause of these fires, but recent studies (Barrett 1980, 1981) point out that Native Americans (Salish and others) were also an important ignition source. Settlement by European Americans became significant in the Bitterroot Valley below Lick Creek starting about 1860, but apparently this had little effect upon the role of fire until about 1900 (Arno 1976). Fire scar studies from similar sites in the Bitterroot Valley indicate that the pattern of frequent surface fires was in effect at least as early as 1500.

In the spring of 1980, Arno and Gruell spent several hours searching the central portion of the photopoint study area for evidence of fire history. They found that large, old fire-scarred stumps (mostly ponderosa pine, but also some Douglas-fir on north-facing slopes) are common throughout the area. Evidently, most of these are the remains of trees cut in the 1907-11 logging, and many of them were scarred by at least 6 to 12 different fires in the 200 to 250 years prior to logging. We cross-sectioned six of the best preserved and most complete fire-scar sequences, four from pitch stumps of ponderosa pine, and two from the bases of living pines. The cross-sections were sanded and annual rings were counted under magnification in order to date the probable year of each fire scar. These fire-scar dates from the individual stumps and trees were then correlated and adjusted slightly to account for minor ring errors as described by Arno and Sneck (1977). This produced a fire chronology for the stand as a whole. The individual fire scar records and the fire chronology are presented in table 1.

These records indicate that light surface fires swept through the forest at intervals averaging 7 years between A.D. 1600 and 1900. One of the cross-sectioned stumps (labeled "below photopoint 6" in table 1) shows 16 fire scars between 1752 and 1890 (fig. 5).

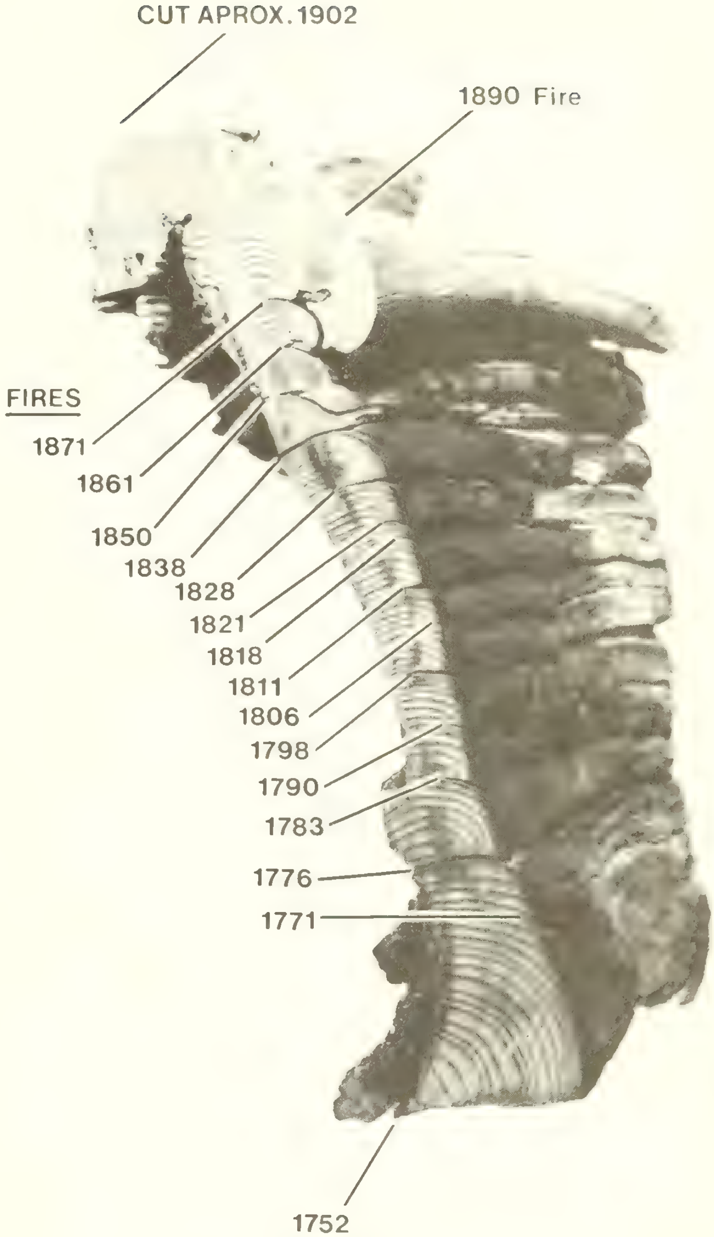


Figure 5.—Cross-section from the ponderosa pine stump below photopoint 6 (table 1) at Lick Creek, showing 16 fire scars between 1752 and 1890.

Table 1.—Fire chronologies for six fire-scarred trees and stumps at the Lick Creek photopoints, Bitterroot National Forest; X = an individual f scar (42 fires between 1600 and 1900 yields a mean interval of 7 years)

Estimated fire year	Live tree at photopoint 3 (cambium 1979)	Stump at photopoint 2 (cut about 1905)	Stump at photopoint 1 (cut after 1903)	Live tree below photopoint 6 (cambium 1979)	Stump below at photopoint 6 (cut about 1902)	Stump at photopoint 8 (cut about 190
1895		X		X		
1890		X		X	X	
1883			X			X
1875		X				
1871	X	X	X	X	X	X
1861			X	X	X	
1856				X		X
1850		X			X	
1846						X
1842			X			X
1838	X	X		X	X	X
1832						X
1828	X				X	
1821	X		X		X	X
1818		X	X		X	
1811					X	X
1806		X	X		X	
1798		X	X		X	X
1795	X		X			X
1790					X	X
1786			X			
1783		X			X	X
1780		X				
1776	X	X			X	X
1771					X	X
1758	X					X
1752	X				X	X
1744	X		X			X
1734			X			
1729						X
1719			X			
1713						X
1707			X			
1702(?)						X(?)
1693						X
1681						X
1672	X					
1657						X
1651						X
1646						X
1642						X
1618						X
1598						X
1586						X
1552						X
1545						X
1444						X
pith date	1648	1724	1617	rotten	rotten	1428

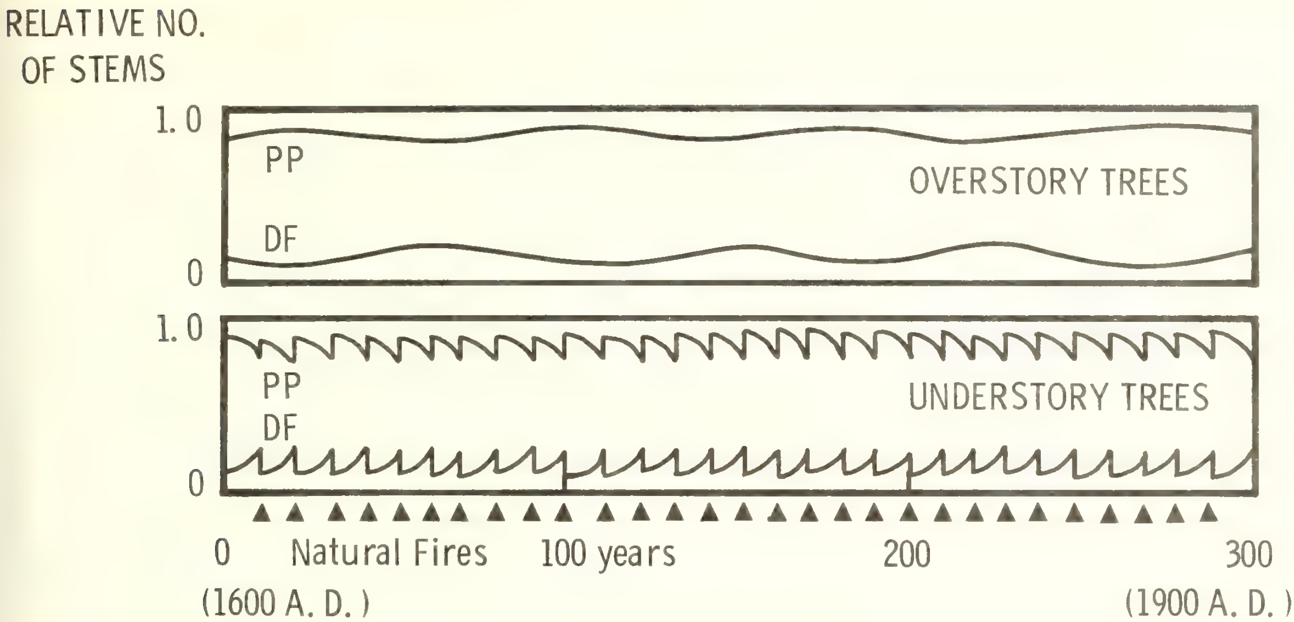


Figure 6.—The effect of succession on relative abundance of ponderosa pine and Douglas-fir at Lick Creek: hypothesized succession with underburns at 5- to 15-year intervals.

Although the sites at Lick Creek are capable of sup-orting both ponderosa pine and Douglas-fir, the pre-1900 e regime brought about development of all-aged (or any-aged) stands of ponderosa pine. Douglas-fir aplings are readily killed by surface fires, whereas some onderosa pine saplings often survive. (Small Douglas-firs e sensitive to fire because of their photosynthetically-ctive bark along with their small buds and fine branch-ts. Ponderosa pines of comparable size have already eveloped a layer of corky outer bark and they have large, otected buds and thicker twigs.) Thus, there was a ontinual selection pressure against Douglas-fir. This henomenon was acknowledged by W. W. White (1924, e footnote 1). Figure 6 depicts relative abundance of ese two conifers in both the overstory and the under-ory during the pre-1900 fire regime. If it had not been for irface fires, the more shade-tolerant Douglas-fir would ave been able to regenerate under the pine and entually dominate the site, as shown in figure 7.

Field observations by Leiberg (1899) and historical counts compiled by Weaver (1974) and Barrett (1980, 981) state that many pre-1900 ponderosa pine/Douglas-fir rests had open, grassy undergrowth, and this is borne it by the 1909 photographs at Lick Creek, as well as by o 1898 photographs taken by Leiberg (1899) in similar rests a few miles north of the Lick Creek area (fig. 8).

The native, dry grassland species—bluebunch wheat-ass, Idaho fescue, and arrowleaf balsamroot (readily entifiable in the early photographs)—formed the under-owth on the drier sites (PSME/CARU-PIPO and SME/SYAL-CARU). The undergrowth on moist habitat pes (PSME/VAGL-ARUV and PSME/VACA) was primarily d-forming (rhizomatous) woodland grasses—pinegrass d elk sedge—along with the low shrubs—kinnikinnick, owberry, white spiraea, dwarf huckleberry, and blue huckleberry. On both dry and moist habitat types, large shrubs like bitterbrush, willow, and serviceberry, as well as understory conifers were killed back by the frequent ground fires.

The 1909 photos, as well as the Leiberg (1899) photos, show that although the understories were open, the stands were heavily stocked with large ponderosa pines. They had clear boles because the lower limbs had been shaded out and possibly scorched by fire. Modest growth rates and relatively high basal areas of tree stems per acre attest that these early stands were fully stocked or overstocked in terms of timber production. Consequently, in addition to fire, dominance of large pines contributed to a lack of tree regeneration and shrubs in the understory. Saplings and shrubs were probably also inhibited by the well-developed overstory canopy and tree root systems utilizing much of the soil moisture and nutrients.

The overstory pines usually lived 300 to 500 years (Arno 1976). They evidently died and were replaced individually or in small groups. When openings occurred, new pines would generally grow and fill them. Some saplings would succumb to damage by the next surface fire, but others would survive. Occasionally, combinations of unusually dry years coupled with epidemics of yellow pine butterfly (*Neophasia menapia*) and mountain pine beetle (*Dendroctonus ponderosae*) may cause substantial mortality as they did in some dry sites in the Bitterroot Valley during the early 1970's. C. A. Wellner (personal communication, USDA Forest Service retiree, Moscow, Idaho) notes that the beetle caused heavy losses at Trapper Creek and in some other areas of the Bitterroot in the mid- to late 1930's, which were dry years. Still, old-growth ponderosa pine forests with open understories perpetuated by surface fires evidently dominated the Lick Creek area for centuries prior to 1900.

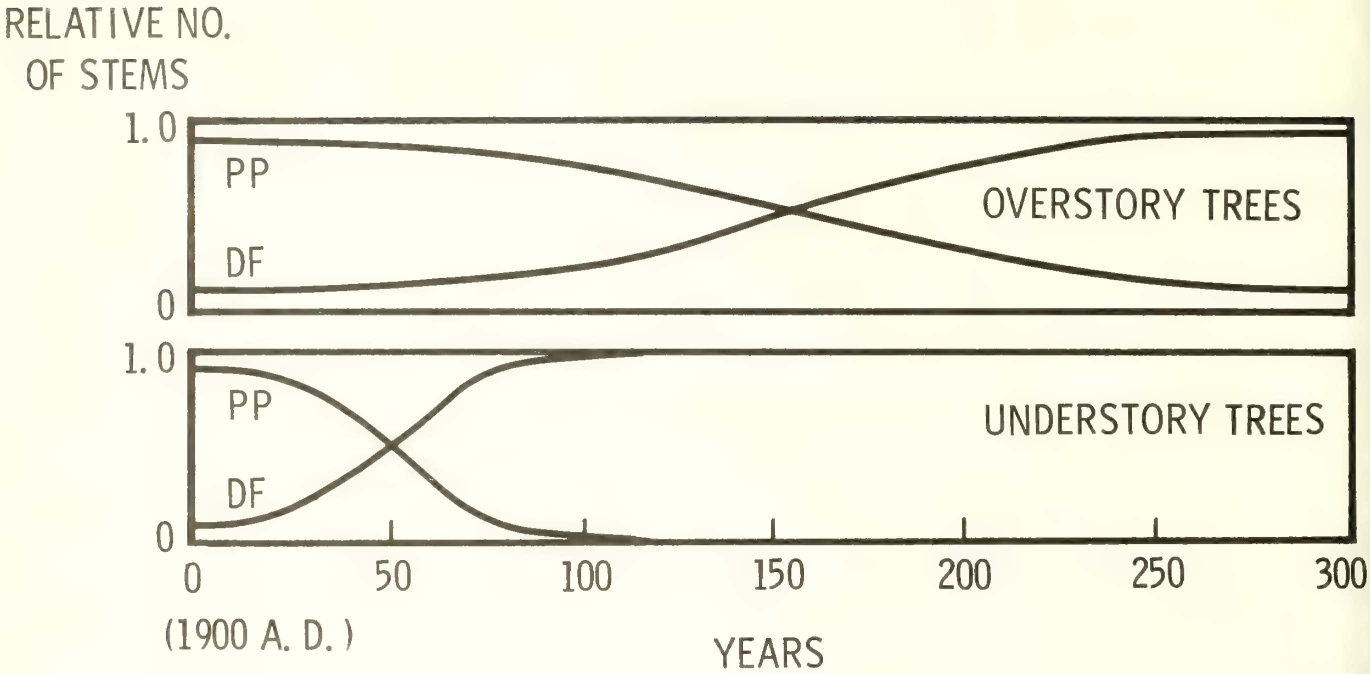


Figure 7.—The effect of succession on relative abundance of ponderosa pine and Douglas-fir at Lick Creek: hypothesized succession with fire control and no cutting.

Figure 8.—Photo by J. B. Leiberg in 1898 showing heavily stocked ponderosa pine stand with open understory in the Bitterroot Valley between Kamas and Lost Horse Creeks.

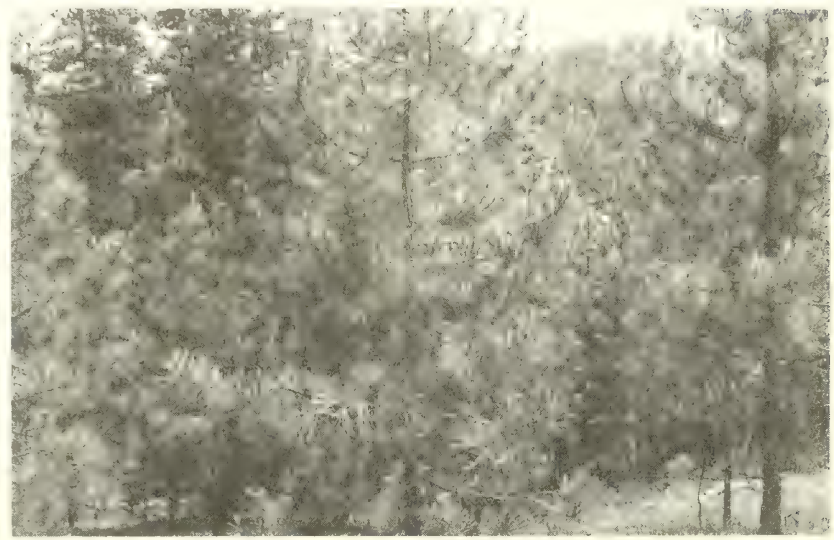
PHOTO RECORD OF PLANT SUCCESSION AFTER TIMBER HARVESTING

Figure 9.—Photopoint 1: 1909-79.

1909.
Camera faces southeast toward Lick Creek scalers' cabin and clearcut on private land in distance. Ground cover is largely herbaceous species with high incidence of lupine. Scattered patches of low shrubs are also evident (PSME/SYAL-CARU h.t.). Scattered willows occupy the more moist sites below Ranger Earl Tanner. A few widely scattered young conifers are also evident. (USDA FS Photo 86467)

1925, 16 YEARS LATER.
Establishment and growth of conifers has resulted in a marked change in the understory. Snag at right center was a living tree in 1909. (USDA FS Photo 204817)

1937, 28 YEARS LATER.
Former view is now almost entirely screened by young ponderosa pine. The herbaceous understory does not appear to be as luxuriant as formerly. Willows in opening at left are considerably larger. (USDA FS Photo 354395)



1948, 39 YEARS LATER.
Continued growth of conifers has resulted in complete closure of understory in midground. Snowberry shrubs are evident. (USDA FS Photo 452646)

1958, 49 YEARS LATER.
Construction of system road has altered the soil surface in foreground. Shelterwood cut in 1952 is not apparent because of screening by young pine. (USDA FS Photo 487741)

1968, 59 YEARS LATER.
A selection cut in 1962 and precommercial thinning in 1966 have opened the stand and allowed appreciable growth. Willows can be seen below road. (USDA FS Photo 518769)

1979, 70 YEARS LATER.
View is once again screened by growth of young pines in foreground that became established on scarified soil following logging. A stand of bitterbrush not pictured behind camera point also regenerated as a result of disturbance. (USDA FS Photo)

Figure 10.—Photopoint 2: 1909-79.

1909.

Looking southwest across open ponderosa pine dominated slopes from a point 75 yards above fig. 9 (dry extreme of the PSME/CARU-PIPO h.t.). Original stand appears to have been quite open before logging. A deeply incised skid trail is evident in midground. A few widely scattered young conifers and willows are growing on slopes below. Recent analysis of stump at feet of Ranger Tanner shows evidence of 5 different wildfires prior to logging. (USDA FS Photo 86475)

1927, 18 YEARS LATER.

Pine regeneration screen view, while some mature trees have fallen to ground. An unidentified shrub now occupies site at right corner of photo. (USDA FS Photo 221277)

1937, 28 YEARS LATER.

View is completely screened by heavily overstocked young pines. Pine at right center has died. Suppressed shrub at right corner of photo persists beneath canopy of young pines. (USDA FS Photo 354396)

1948, 39 YEARS LATER.

Heavy stocking of young pine appears to have stagnated. Note fire mosaic on far slope that apparently occurred in 1875. Pine at left center has died. (USDA FS Photo 452645)

1958, 49 YEARS LATER.

A shelterwood cut in 1952 removed tree at right and snag is also gone. Young pines have grown modestly despite heavy overstocking, while buildup of ground fuels is evident. (USDA FS Photo 487742)

1968, 59 YEARS LATER.

Wyman Schmidt views selection cut in 1962 that removed the mature pine that had been present in left corner of photo since 1909. Precommercial thinning in 1966 has opened up foreground. Ground fuels have increased by addition of slash. Thinning has allowed leave trees to put on good growth. (USDA FS Photo 518776)

1979, 70 YEARS LATER.

Thinning of the young pine stand has resulted in establishment of bitterbrush in left foreground and to right of old stump. Willows are also evident in foreground. Growth of young pines is accelerating. (USDA FS Photo)

Figure 11.—Photopoint 3: 1909-79.

1909.
A northwesterly view of cleanup operation following cutting in an open-grown ponderosa pine (PSME/CARU-PIPO h.t.). Although slash piles obstruct clear view, the understory apparently lacks shrubs. Perennial grasses and forbs predominate. (USDA FS Photo 86466)

1927, 18 YEARS LATER.
Young Douglas-fir and ponderosa pine have become established in the background. A few young pine are also scattered through foreground. Willows 4-6 feet in height now occupy site at right midground of photo. Others of smaller growth form are also evident. Kinnikinnick predominates at base of tree at right foreground. Litter is beginning to accumulate. (USDA FS Photo 221278)

1937, 28 YEARS LATER.
Ponderosa pine and Douglas-fir regeneration continues to close the understory in background. Growing conditions for young trees and willow have been enhanced by mortality and windthrown standing timber. Note growth of willow in right midground. Litter

1948, 39 YEARS LATER.
Growth of understory now obstructs view of background. Willow at right midground is obscured by young pines. (USDA FS Photo 452643)

Figure 11—Continued

1958, 49 YEARS LATER.
A shelterwood cut was made in this general area in 1952, but its influence is not evident. Continued growth of young conifers has resulted in a thicker understory. The large willows at right are becoming senescent. Litter buildup is heavy. Debris may be the result of 1952 logging outside view of photo. Kinnikinnick continues to predominate at base of tree at right. (USDA FS Photo 487746)

1968, 59 YEARS LATER.
A selection cut in 1962 and precommercial thinning in 1966 opened up the area considerably. Note decomposition of larger materials. Large willows at right contain many dead branches, but removal of young conifer competition has provided improved growing conditions. A bitterbrush shrub has become established near tree in right foreground. (USDA FS Photo 518768)

1979, 70 YEARS LATER.
Overstory canopy is more closed as a result of tree growth. Willows at right show some new growth. New willows are evident in foreground, while the one in front of tree at left which became established between 1909 and 1927 is slightly larger than in former years. Note the increased size of the bitterbrush plant (USDA FS Photo)

Figure 12.—Photopoint 4: 1909-79.

1909.
Looking northeast through a more heavily stocked ponderosa pine stand at a point about one-half mile northeast of fig. 11. The ground cover around C. H. Gregory (in distance) and W. W. White is predominantly herbaceous species with a high incidence of balsamroot (PSME/CARU-PIPO h.t.). The dark low-growing shrubs around White appear to be snowberry. Large willows are evident on left edge of photo and in front of White. (USDA FS Photo 86469)

1927, 18 YEARS LATER.
The two willows in 1909 scene have grown considerably and now contain many dead branches. Other willows have become established in midground, while young ponderosa pine can be seen in localized areas. The herbaceous ground cover persists. Taken later in the season, this view pictures balsamroot at a cured stage of growth. Note fire-scarred stump on right. (USDA FS Photo 221280)

1938, 29 YEARS LATER.
Young pine growth is beginning to occupy localized sites in understory. A tree on right has blown down, and the willow in foreground that was present in 1909 has become senescent. In foreground, the low shrub component is less evident, but this may be a seasonal difference. (USDA FS Photo 354400)

1948, 39 YEARS LATER.
Two mature pines have fallen to ground. Growth of young pines are closing in portions of understory. Young pine at right foreground is screening senescent willow. Herbaceous plants and snowberry in foreground have put on good growth. (USDA FS Photo 452641)

Figure 12.—Continued

1958, 49 YEARS LATER.
A shelterwood cut in 1952 removed several of the merchantable trees and left slash on the ground. Plants occupying sites near left edge of photo appear to be bitterbrush. (USDA FS Photo 487747)

1968, 59 YEARS LATER.
A 1962 selection cut and 1966 percommercial thinning have resulted in a more open landscape with increasing slash on the ground. The bitterbrush plants are more evident, while willows in the midground have been favorably influenced by removal of young conifers. (USDA FS Photo 518770)

1979, 70 YEARS LATER.
Rapid establishment and growth of new conifers has screened the open view of 1968. Growing conditions for bitterbrush and willow have deteriorated because of competition from conifers for sunlight and moisture. Partial cutting and thinning in 1952, 1955, 1962, and 1966 have allowed more conifer regeneration than the early, light 1906-09 cut. (USDA FS Photo)

Figure 13.—Photopoint 5: 1909-79.

1909.
The camera faces south-southeast into the Lick Creek drainage. Camera point for fig. 14 is below and to the left. E. C. Clifford examines partial cut which opened up ponderosa pine stand (PSME/CARU-PIPO h.t.). (Note clearcut in distance pictured in fig. 14.) Understory is predominantly perennial grasses with high incidence of balsamroot. A low-growing willow can be seen at left foreground, while other widely scattered willows are evident in background. (USDA FS Photo 86473)

1927, 18 YEARS LATER.
Ponderosa pine regeneration is profuse in midground. Willow in foreground has grown considerably as has another on left edge of photo behind tree. Down trees and broken-top pines (center and right) evidently resulted from wind damage after stand was opened. (USDA FS Photo 221281)

1938, 29 YEARS LATER.
Young ponderosa pine growth continues, at a modest rate. Although willow at left has not leafed out, it appears to contain dead branches. Gradual loss of overstory trees continues. (USDA FS Photo 361707)

1948, 39 YEARS LATER.
Understory is now dominated by young ponderosa pine. The pine in center foreground that was apparently dead in 1938 has lost its bark, while the two trees to the right have toppled. Opening of the overstory may have improved growing conditions for herbaceous plants. (USDA FS Photo 452650)

1958, 49 YEARS LATER.
Photo was taken too far to the left, but it does show that young ponderosa pine have grown well, considering that they are heavily overstocked. The increased canopy in foreground appears to be restricting growth of herbaceous plants. (USDA FS Photo 487743)

1968, 59 YEARS LATER.
Construction of road in 1967 and overstory removal in 1968 resulted in considerable site modification. The willow in foreground of 1909 scene in front of William Chord had persisted despite heavy pine competition and is now of large growth form with little foliage near the ground. Mullein in foreground seeded in on disturbed soil. (USDA FS Photo 518774)

1979, 70 YEARS LATER.
Opening of stand in 1968 allowed good growth on pines and release and establishment of willow. The large willow in foreground shows new growth near ground level from suckering. Spotted knapweed dominates disturbed site in foreground. Far slope that was clearcut in 1909 is now covered by pole-size conifers. (USDA FS Photo)

Figure 14.—Photopoint 6: 1909-79.

1909.
The camera faces southeast in a ponderosa pine stand (PSME/CARU-PIPO h.t.) that has been selectively logged. W. W. White assesses the work. Understory vegetation is largely comprised of herbaceous species with balsamroot evident. Low shrubs in immediate foreground cannot be identified. Note clearcut on private land in distance (USDA FS Photo 86471)

1925, 16 YEARS LATER.
Ponderosa pine seedlings have become established, while willow is evident, particularly in area formerly covered by slash pile at right. Blowdown has occurred in foreground while distant slopes (in the clearcut) support scattered tall shrubs and conifer regeneration (USDA FS Photo 204818)

1938, 29 YEARS LATER.
The open parklike appearance of the understory has been replaced by dense patches of young ponderosa pine. Willows have grown appreciably, but are not yet leafed out in this April scene. Blowdown of an occasional overstory pine is resulting in reduced crown [illegible]

1948, 39 YEARS LATER.
Growth of young ponderosa pine masks much of former view. Ground cover around Kenneth Boe is largely herbaceous species. Clearcut in distance now supports a developing conifer stand. Willows are suppressed. (USDA FS Photo 452648)

1958, 49 YEARS LATER.
The camera has swung too far to the left. Increased development of pine understory has created ladder fuels. Shading and litter accumulation apparently has inhibited herbaceous growth. (USDA FS Photo 487744)

1968, 59 YEARS LATER.
Overstory removal in 1968 resulted in a landscape that is dominated by young ponderosa pine. Foreground has been heavily scarified by tractor skidding. After 59 years, willow on edge of stand at left center of photo contains much dead material. (USDA FS Photo 518772)

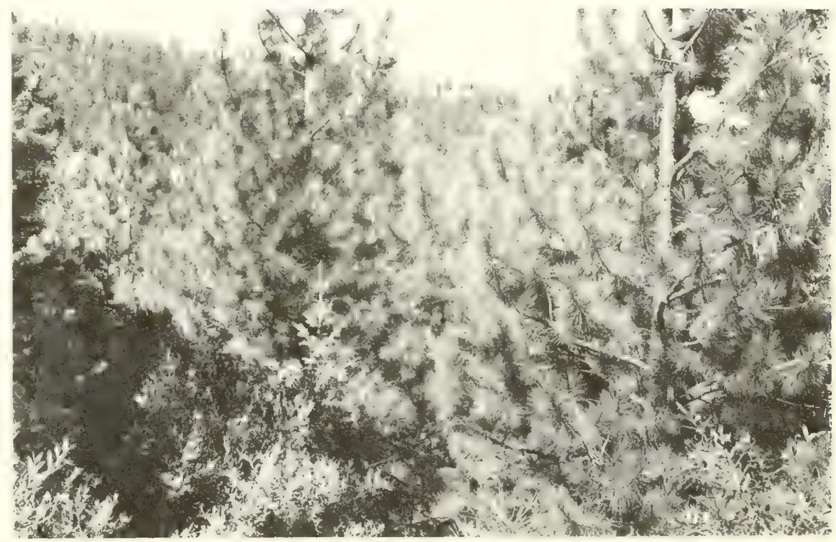
1979, 70 YEARS LATER.
Ponderosa pine growth response to overstory removal has been very good despite poor condition of some trees in 1968. Scarified soil in foreground allowed establishment of pine seedlings, bitterbrush, willow, pinegrass, and knapweed. (USDA FS Photo)

Figure 15.—Photopoint 7: 1909-79.

1909.
Looking north across part of 1906 clearcut on private land. Photopoints 5 and 6 are in conifers at right in distance. Foreground supported ponderosa pine and a higher complement of Douglas-fir than on other sites in this photo series (PSME/VAGL h.t.). Residual conifers below are mostly Douglas-fir. Scattered patches of aspen and willow have been released following logging. Slopes below support luxuriant ground cover of pinegrass and low shrubs. A network of haul roads and skid trails are visible (USDA FS Photo 86479)

1925, 16 YEARS LATER.
Conifer regeneration has developed more rapidly on north slope and valley bottom than on the distant south slope. Douglas-firs are mostly represented. Aspen and willow have grown profusely. Note large willow in foreground. (USDA FS Photo 204830)

1938, 29 YEARS LATER.
Conifers now dominate slope below and valley bottom. Ponderosa pines that were not visible in 1925 are now apparent in immediate foreground. Most of south-facing slope in convex slopes. Large willow in foreground has not leafed out. (USDA FS Photo 361705)



1948, 39 YEARS LATER.
The original scene is now almost completely screened by vigorous young conifers. Willows in foreground are still in a healthy condition. (USDA FS Photo 452638)

1958, 49 YEARS LATER.
Conifers show further height and diameter growth, whereas willow is declining. (USDA FS Photo 487749)

1968, 59 YEARS LATER.
Precommercial thinning was carried out in 1968, but photo indicates insignificant removal on this site. Willows in foreground are leafed out and therefore more evident. (USDA FS Photo 518778)

1979, 70 YEARS LATER.
Canopy appears less dense than in 1968. (USDA FS Photo)

Figure 16.—Photopoint 8: 1909-79.

1909.
Looking east-southeast at a selection cut in primarily ponderosa pine (PSME/VACA h.t.). Pole-size Douglas-fir can be seen at right. Ground cover is herbaceous species with low shrubs and scattered small willows and snowberry. A large willow is growing in foreground on left. Charred log at the foot of W. W White (center), and snag at left center of photo attest to past wildfire. Clifford, the first planting specialist in the Northern Region, is seated on a charred log. (USDA FS Photo 86470)

1927, 18 YEARS LATER.
Willows are now a conspicuous part of the understory in midground, while foreground has taken on a more grassy appearance. Douglas-fir and ponderosa pine regeneration are contributing to a much more developed understory than before (USDA FS Photo 221285)

1937, 28 YEARS LATER.
Young conifers are beginning to dominate the understory; willow has grown appreciably in midground. Litter accumulation is evident in foreground, while the tree canopy on skyline is less dense because of mortality and windthrow. (USDA FS Photo 354397)

1948, 39 YEARS LATER.
Willows are beginning to die back. Competition from young conifers is becoming intense. Litter accumulation in foreground includes a high incidence of pine cones. (USDA FS Photo 452649)

1958, 49 YEARS LATER.
The open understory of 1909 has been replaced by a dense growth of young conifers. Willows are not leafed out, but nonetheless contain many dead branches. Although grasses persist in foreground, their growth seems to be inhibited because of accumulative litter. (USDA FS Photo 487748)

1968, 59 YEARS LATER.
Precommercial thinning and pruning were carried out in 1968. The removal of trees in foreground, dozer scarification, and deposition of material from road construction resulted in establishment of mullein, thistle, and many ponderosa pine seedlings. Young willows can be seen at left center of photo. (USDA FS Photo 518771)

1979, 70 YEARS LATER.
Photo documents how ponderosa pine can successfully regenerate on a disturbed (scarified) site. The ground cover in immediate vicinity is largely knapweed, dogbane, and Canadian thistle, which are disturbance indicators. (USDA FS Photo)

Figure 17.—Photopoint 9: 1909-79.

1909.
A northwest view back toward previous camera points. Ground cover is comprised of herbaceous species including balsamroot and low-growing snowberry and spirea (PSME/SYAL-CARU h.t.). Young Douglas-fir can be seen in understory. (USDA FS Photo 36478)

1927, 18 YEARS LATER.
Willow are now predominant in opening at left in midground and are also evident in foreground. A few bitterbrush plants are also present in foreground. Douglas-fir regeneration is well established. (USDA FS Photo 221284)

1938, 29 YEARS LATER.
Douglas-fir growth is competing with willow and bitterbrush. Both shrubs have grown considerably, but dead branches are particularly evident within canopy of several

1948, 39 YEARS LATER.
Young Douglas-fir stand has overtopped much of the shrub complement. A few bitterbrush and willow plants persist in openings, while snowberry is growing vigorously.

1958, 49 YEARS LATER.
Early skyline view has been completely screened by growth of conifers. Closure of understory has resulted in further deterioration of large shrubs. Note dead willow at left center of photo. (USDA FS Photo 487739)

1968, 59 YEARS LATER.
Precommercial thinning in the 1960's resulted in improved conditions for willow, bitterbrush, and other understory plants. Slash has increased ground fuels. (USDA FS Photo 518777)

1979, 70 YEARS LATER.
Growth of Douglas-fir screens view. These ladder fuels are beginning to create a hazard to second growth timber and the few trees left from the original stand. (USDA FS Photo)

Figure 18.—Photopoint 10: 1909-79.

1909.
Facing nearly due west from ridge northeast of Como Lake. Light selection cut in open ponderosa pine. Ground cover is comprised of perennial grasses and forbs, including balsamroot (PSME/CARU-PIPO h.t.). A few low-growing bitterbrush plants can be seen in the vicinity of horses and in distance on left. A group of willows can also be seen behind horseman at left center. (USDA FS Photo 87357)

1925, 16 YEARS LATER.
Bitterbrush plants on left and willow in distance, more evident in this winter scene, have increased in size. Young conifers are beginning to fill in the understory in background. (USDA FS Photo 204815)

1938, 29 YEARS LATER.
Several pines in foreground have been cut, some have died, and others have fallen to the ground. Ponderosa pine and Douglas-fir regeneration is profuse, while the willow in ... and windfall have resulted in an increase in heavy fuels. Mullein can be seen in left

1948, 39 YEARS LATER.
Former open view is screened by growth of young conifers. Bitterbrush plants have continued to grow, but are beginning to receive competition from conifers for space. ... Dead trees have toppled, adding to

Figure 18.—Continued

1958, 49 YEARS LATER.
Growth of young ponderosa pine and Douglas-fir dominate skyline, thereby obscuring view of the few remaining mature ponderosa pine in distance. Competition by young pines in foreground has apparently caused several of the bitterbrush plants to deteriorate. Heavy ground fuels show considerable decomposition. (USDA FS Photo 487738)

1968, 59 YEARS LATER.
Precommercial thinning and pruning in 1968 removed mature pines and opened up young pine stand. This benefited some bitterbrush plants (reference to other photo sequences), but those in left foreground under and near leave trees show further deterioration. Slash has added to heavy fuels, while down material is more decomposed. (USDA FS Photo 518767)

1979, 70 YEARS LATER.
Understory is dominated by increased pine growth that is shading out bitterbrush. Past disturbance has allowed knapweed to predominate in foreground. (USDA FS Photo)

Figure 19.—Photopoint 11: 1909-1948.

1909.
View is south-southeast through an open ponderosa pine stand selectively cut in 1907 or 1908 (PSME/SYAL h.t.) Luxuriant grass/forb cover reflects prelogging conditions. Note fire-scarred ponderosa pine and lone Douglas-fir seedling immediately to the left of W. W. White. A low-growing bitterbrush plant can also be seen between White and stump. (USDA FS Photo 86480)

1927, 18 YEARS LATER.
Douglas-fir regeneration has resulted in marked change in understory. Grass/forb ground cover persists, but now bitterbrush and snowberry are more evident in foreground. Pine stand is somewhat less dense because of cutting or windfall. (USDA FS Photo 221282)

1938, 29 YEARS LATER.
Douglas-fir understory continues to increase in size and density. Some overstory trees continue to die. (USDA FS Photo 361703)

1948, 39 YEARS LATER.
Original view is now screened out by growth of young Douglas-fir. Ground cover in foreground now has considerable numbers of low shrubs. Snowberry appears to predominate. (USDA FS Photo 452640) (Entire 70-year sequence not replicated.)

TERPRETATIONS
‑ VEGETATIVE CHANGE

'he 1907-11 logging operations and subsequent lack of und fires dramatically changed the patterns of plant ccession at Lick Creek. Large quantities of overstory es were felled, creating sizable openings. Logs were dded and slash was burned in piles, locally (over a all percentage of the ground) scraping off or consum- surface vegetation, pine needle litter, and humus, and osing mineral soil. The photo sequences covering the t 40 years show these results: Tall shrubs (especially uler willow) and tree regeneration became established lirect proportion to the amount of stand opening and und disturbance. The response of tall shrubs and tree eneration was most vigorous on the moist habitat es.

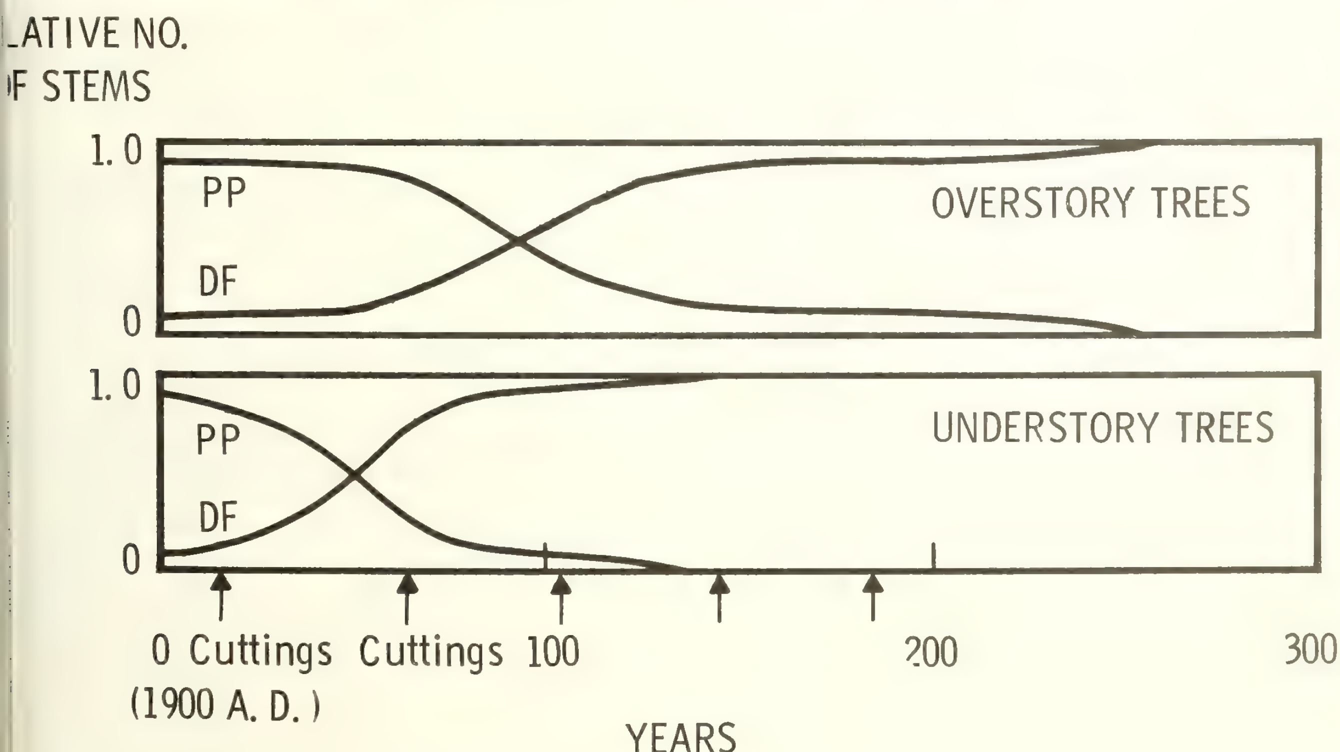
:ven though overstory Douglas-firs were mostly ioved in the 1907-11 logging, Douglas-fir regeneration 'eased markedly thereafter. This regeneration is a ult of: (1) the absence of surface fires, and (2) the ning up of the stand through logging. Figure 20 icts the probable tree succession associated with fire trol and partial cutting in this forest type. Note that shows a speedup in natural succession, as illustrated igure 7. Douglas-fir regeneration increased markedly the moist habitat types and under lighter cutting tments. Pine regeneration was more successful in the habitat types and with greater stand opening and site urbance.

t some photopoints several of the large pines left r early logging died from windthrow and mountain beetle attacks. This provided further opportunity for erstory trees and shrubs to develop. Also, the photo sequences allow observation of the slow progression of death, decay, and downfall including disintegration of stumps.

On dry habitat types, the original dry grassland type of undergrowth was replaced within a few decades by conifers and shrubs, including antelope bitterbrush. Often, dense pole stands developed after 30 to 40 years, tall shrubs began to be shaded out, and undergrowth, in general, became sparse. After thinning of the poles and removal of the remaining large pines in the 1950's and 1960's, the tall shrubs and other undergrowth became more dense. Today, after thinning, the remaining pole-size conifers generally show good vigor. Composition has shifted toward mixed stands of ponderosa pine and Douglas-fir, and with continued partial cuttings and lack of surface fires, Douglas-fir will probably dominate on many sites.

In general, the photos show that the dry habitat types have changed from original dominance by large ponderosa pine with bunchgrasses beneath to thrifty pole-size pine and Douglas-fir with scattered willow and undergrowth of sylvan species like pinegrass, elk sedge, and snowberry. Bitterbrush occupies localized dry sites that were heavily scarified.

The transition shown on the moist habitat types begins with stands dominated by large ponderosa pines and with some Douglas-fir. These had open understories and ground cover composed of low shrubs and pinegrass. After the 1907-11 logging and subsequent fire suppression, vigorous pole/tall shrub communities of Douglas-fir, ponderosa pine, and Scouler willow developed, with a low shrub and pinegrass ground cover beneath. Mechanical thinning of the poles since 1950 has kept the willow from becoming badly suppressed.



F ure 20.—The effect of succession on relative abundance of ponderosa pine and Douglas-fir a Lick Creek: hypothesized succession with fire control and partial cuttings.

FUELS CHANGE

Logging and the exclusion of wildfire resulted in a significant increase in downed woody material and in live fuels in Lick Creek. William C. Fischer, fuels specialist at the Northern Forest Fire Laboratory in Missoula, Mont., evaluated the condition of fuels by referring to his "Photo Guide for Appraising Natural Fuels in Montana Forests" (Fischer 1981). This evaluation showed that changes have been variable at photopoints 1 through 11 (figs. 9 through 19), as shown in the following tabulation:

	Hazard rating	
Photopoint	1909	1979
1, 2, 7, 9	low	high
8	low	medium-high
5, 6, 11	low	medium
3, 4, 10	low	low

The greatest increase in downed woody material has occurred in localized areas where heavy accumulations of untreated thinning slash were left following entries in the 1950's and 1960's. Deterioration of this slash has resulted in reduced hazard at three camera points (figs. 11, 13, and 18), but the increase in slash and live fuels over 1909 conditions has resulted in a high potential for cambial kill of small trees.

The major fuels change was the development of live ladder fuels, which increased the susceptibility of the original stand to crown fire. The potential for crown fire was highest in the early 1950's prior to logging and thinning. Overstory removal and thinning in the 1950's and 1960's reduced the potential of crowning in some localities, but establishment of ladder fuels in recent years is again increasing this potential. Because of fuel discontinuity, the likelihood of a crown fire occurring, given average burning conditions, is not great. However, a fire driven by high winds and burning under extremely dry conditions could crown and destroy second-growth timber being managed for future harvest.

The photo record strongly suggests that, prior to 1909, light loading of downed woody material and lack of ladder fuels precluded the development of crown fires. Partial cutting and fire exclusion in the ponderosa pine type results in increased downed woody material and ladder fuels. If future crown fires are to be averted, logging slash should be treated and ladder fuels thinned periodically. The judicious use of underburning at appropriate intervals (e.g., 25 to 30 years) has the potential for reducing both ground and ladder fuels as well as achieving benefits for wildlife and recreation.

Figure 21 shows hypothesized stand composition in such forests under a program of partial cuts and prescribed underburns intended to favor regeneration of ponderosa pine. The underburns would reduce fuel hazards and expose mineral soil to allow for tree regeneration. The underburns would differentially kill more of the understory Douglas-fir than pine, and the silvicultural approach would mimic the pre-1900 ecosystem processes (fig. 6).

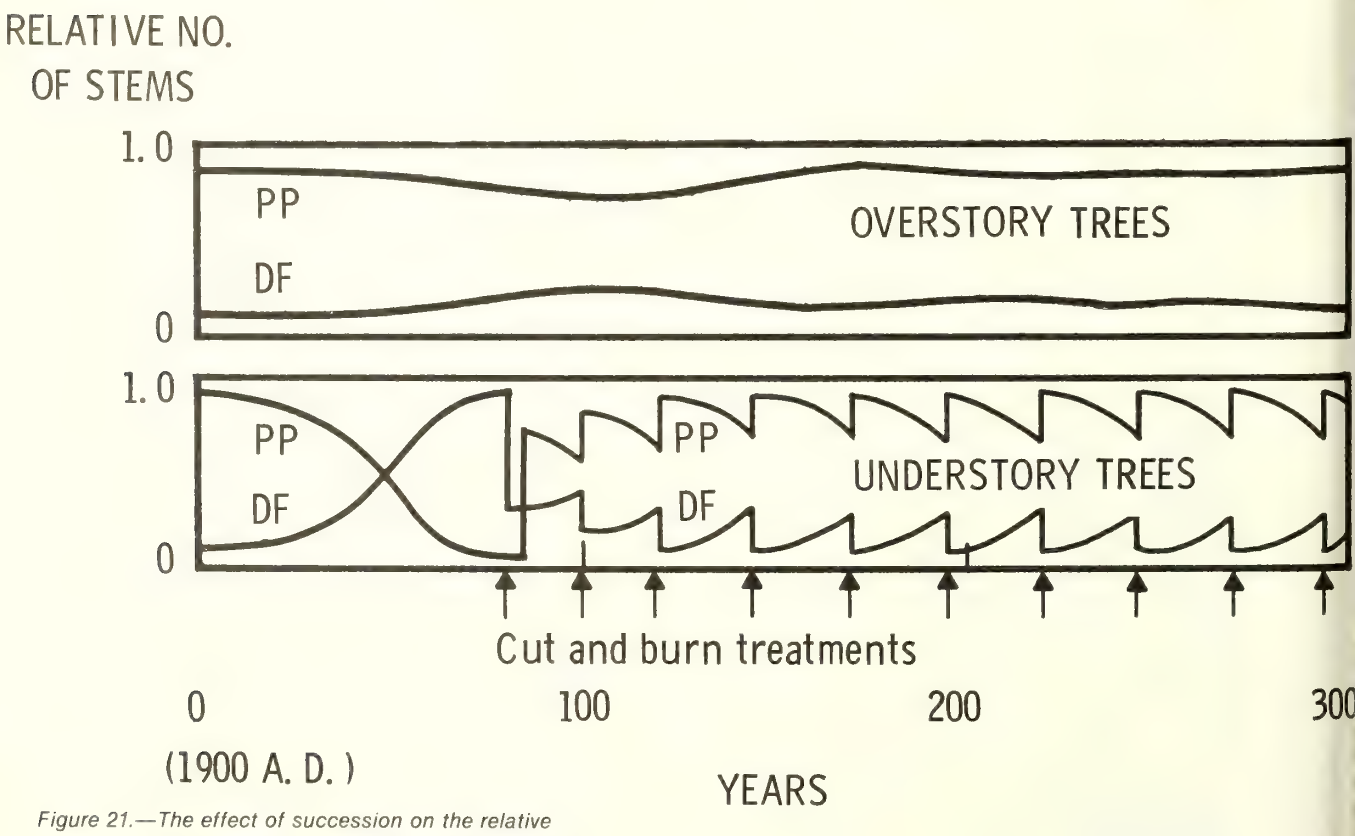


Figure 21.—The effect of succession on the relative abundance of ponderosa pine and Douglas-fir at Lick Creek: a hypothetical selection system and prescribed underburning to favor ponderosa pine.

ANAGEMENT IMPLICATIONS

mber

.ong-term interpretations of timber management in the k Creek area, which is fairly typical of the ponderosa e/Douglas-fir type in western Montana, are based on (1) anges observed in repeat photos over a long period of e, (2) timber stand data collected 40 years after the ial cuttings, and (3) short-term data from limited follow- studies. The key to the interpretation lies in the long- n observations made possible with the photos.

deally, a full range of even-aged and uneven-aged tems would have been established, including clear- ting, shelterwood, seed tree, single tree selection, and up selection. Although this was not the case, some of initial partial cuttings (single tree selection) did create ditions similar to the systems mentioned and provided ne management information for those systems.

'artial cutting practices on the Lick Creek area were jely successful in meeting timber management objec- s. Although timber goals were not well defined in the records, managers aimed at maintaining reasonable wth for subsequent harvests, at regenerating the site, l at maintaining ponderosa pine as a major component he stand. Total net board-foot growth up to the time of second round of cuttings was nothing spectacular erage of 66 bd.ft. per acre [163 bd.ft./ha] annually). Response following the second cutting was more en- raging, with values of 150 to 235 bd.ft. per acre (370 to bd.ft./ha). This reflects a younger, more vigorous nd that is better able to capitalize on the growth poten- of the site. For comparison, a 200-year-old, fully- cked stand on similar site quality should produce ut 200 bd.ft. per acre (494 bd.ft./ha) according to Meyer 38). Considering age, vigor, and postharvest stocking of original old-growth stand, growth appears reasonable. s forest was beyond the age when the most significant wth response could be expected.

ngrowth into commercial sizes contributed only a or part of the total volume growth following the inal cutting. Past fires had largely excluded younger nd components. Thus, there were only a few young s capable of capitalizing on the growing space vided by the harvest cuttings. However, younger nds now coming into their own can be expected to duce at higher cubic-volume rates than their over- ure predecessors. Board-foot values become less aningful (because this measure applies to commercial material) than cubic-foot as stands are converted to nger age and size classes.

artial cuttings successfully reduced anticipated tree tality at Lick Creek by harvesting high-risk trees. This ows the same pattern noted by Johnson (1972) in his uations of the western pine beetle (*Dentroctonus icomis*) and mountain pine beetle (*Dendroctonus derosae*) in nearby areas of the Bitterroot. Without the ial cuts, natural mortality would likely have been sub- tial in these old-growth forests. As the area is verted to younger and more vigorous stands, however, less natural mortality can be expected.

onderosa pine regenerated within the first 10 years r harvesting when the canopy was opened and mineral soil had been exposed by logging. As a general rule, the more drastic the treatment, the more it favored ponderosa pine regeneration. Cone crop size, timing, and seed distribution were apparently important factors influencing regeneration on the disturbed sites. In fact, logging damage and release of the seed-bearing trees may have stimulated additional seed production. Later studies indicated that at least some ponderosa pine, particularly the younger trees, respond to these stimuli.

Frequent ground fires in the past had kept the more fire-susceptible Douglas-fir as a minor stand component. As a result, Douglas-fir seed was likely minimal after the first cutting. Douglas-fir can regenerate on much the same site, stand, and seedbed conditions as ponderosa pine, but is much more tolerant of shade and has less stringent seedbed requirements than ponderosa pine. Thus, silvicultural practices that leave heavy overstories with little or no seedbed preparation discriminate against ponderosa pine and provide Douglas-fir a distinct advantage. The virgin stand conditions where fire played a major role provided an exaggerated advantage to ponderosa pine that no longer exists under intense fire control. Under light partial cuttings with little or no site disturbance, Douglas-fir regeneration can be expected to occupy increasing proportions of the stand with a corresponding decrease in ponderosa pine.

In terms of total volume growth, there seems to be little advantage or disadvantage in favoring ponderosa pine over Douglas-fir. Although ponderosa pine was a higher value species than Douglas-fir, price differences between the two species are gradually diminishing. In fact, young and fast-growing ponderosa pine ("bull pine" in the timber trade) is less valuable than young Douglas-fir.

In addition to species value differences, there are also important disease and insect factors that justify regulating species composition. As noted by White (1924, see footnote 1), "Douglas-fir was badly infected with witch's broom (dwarf mistletoe *Arceuthobium douglasii* Engelm.) and seldom attained good size and form." Selective cuttings seldom remove all sources of dwarf mistletoe that infect the understory Douglas-fir. Also, advance regeneration in dwarf mistletoe-infected stands is nearly always infected prior to harvest. Thus, complete removal of the infected overstory can still leave a management problem where advance regeneration is retained following harvest cuttings. In addition, with dwarf mistletoe present in the stand, selection cuttings may actually accelerate spread of the disease. Thus, silviculture practices that shift stand composition toward Douglas-fir concurrently increase susceptibility of the stand to dwarf mistletoe.

Uneven-aged management of these forests is threatened by the western spruce budworm (*Choristoneura occidentalis*). Douglas-fir is the primary host of budworm in most of the Northern Rockies. Budworm larvae disperse particularly well in the layered stands created by uneven-aged management such as the Lick Creek partial cuttings. In fact, partial cutting methods commonly practiced for most of the first half of this century, when coupled with intense fire control, undoubtedly contributed substantially to the perpetuation of the 4 million acres of annual budworm defoliation. These practices not only produced stand structures suitable for budworm, they

also increased the proportion of tolerant tree species—the favorite hosts of budworm. Thus, most of the known ecological niches needed by budworm are adequately provided through uneven-aged management.

It appears that all of the silvicultural systems could be workable in this forest type when coordinated with stand composition, vigor, site, disease, and insect conditions. Defining the long-term objectives is the key to choice of silvicultural prescriptions. Once the management objectives are set, these observations of timber and other resources on Lick Creek provide bases for management decisions in the ponderosa pine/Douglas-fir forests of the Northern Rockies.

Wildlife

Wildlife species have particular habitat requirements that are closely associated with vegetative type and structure. Some species such as the pileated woodpecker have specialized requirements. Others like the robin utilize a wide variety of habitats. Because of variation in habitat requirements, we can expect wildlife species to respond differently to vegetative change, depending upon the nature of the disturbance, time since disturbance, and resulting successional stage.

Fire history research and the photo record demonstrate that frequent low-intensity surface fires kept the Lick Creek understory open prior to logging in 1907-11. These light disturbances resulted in a fairly stable environment in which wildlife populations would not be expected to change significantly over time. Logging and the exclusion of wildfire have brought about marked changes in vegetation. These pronounced changes probably resulted in significant changes in populations of many wildlife species. The following interpretations are based on wildlife habitat requirements and known vegetative trends.

SMALL MAMMALS

Wildlife species with minimal cover requirements would be favored by frequent low-intensity ground fires. Small mammal research suggests that frequent fires in earlier years insured perpetuation of openings essential to the needs of ground squirrels, pocket gophers, and deer mice (see appendix I for common and scientific names of wildlife). These species require minimal cover and tend to increase following opening of the forest canopy and an increase in herbaceous plants (Barnes 1974; Dimock 1974; Davis 1976). Closure of the forest canopy in the 1940's, 1950's, and in recent years has reduced the available habitat for these wildlife species.

Frequent ground fires would have displaced small mammals that require litter and humus for cover. Shrews are temporarily eliminated or displaced from sites where fire has removed the duff and ground vegetation and will not return until ground cover develops (Black and Hooven 1974). Voles of the genus *Microtus* are also associated with the organic layer and are temporarily eliminated by a hot ground fire (Dimock 1974). The increase in litter and humus since 1909, resulting from fire exclusion and periodic logging, has undoubtedly been favorable to these small mammals.

Golden-mantled ground squirrels and chipmunks prefer openings, but are reluctant to move very far from fallen trees, limbs, or shrub cover. Frequent ground fires may have temporarily displaced these species, but the subsequent opening of the tree canopy and increase in dow woody material would favor their return (Davis 1976).

The open understory of earlier years would have been marginal habitat for cottontail rabbits and snowshoe hares. Both species are dependent on shrubs and young trees for food and protection from predators (Costa and others 1976; Grange 1965). Successional changes resulting from logging have been particularly beneficial for snowshoe hares since population highs often coincide with young pole-sized conifers (Scotter 1964; Fox 1978). Unburned slash piles in localized areas complemented cover requirements. Vegetal trends have also benefited the porcupine which prefers young conifers.

Both the red squirrel and the flying squirrel are dependent upon mature or old-growth forests that provide con producing trees and nesting cavities. The presettlement, low-intensity ground fires may have promoted populatio stability by reducing fuels and assuring perpetuation of mature conifer stands. The removal of trees by logging largely eliminated nest trees and displaced squirrels in localized areas. Development of second-growth pine stands appears to be providing sufficient cone crops fo sustaining squirrel populations.

CARNIVORES AND RAPTORS

Various carnivores and raptors, such as the longtail weasel, bobcat, coyote, sharp-shinned hawk, Cooper's hawk, and the great horned owl frequent the Lick Creek area. These predators are opportunists that respond to changes in abundance of prey. Periodic increases in pre resulting from opening the tree canopy have apparently benefited this group of wildlife species.

BIRDS

Breeding bird populations usually respond to change in the forest structure. Bird response by feeding habits changes in structure was evaluated by Sidney Frissell, School of Forestry, University of Montana.

During the first decade or two after partial cutting in 1907-11, much of the Lick Creek area was in a single-st stand of varying canopy coverage. The understory and openings contained few large shrubs (figs. 9 through 14 18 and 19). This structure type favors the following kind of birds:

Ground feeders
common flicker
Swainson's thrush
mountain bluebird
dark-eyed junco
chipping sparrow

Foliage feeders
blue grouse
mountain chickadee
ruby-crowned kinglet
warbling vireo
yellow-rumped warbler
western tanager
Cassin's finch
pine siskin
red crossbill

Air feeders
olive-sided flycatcher

Bark feeders
red-breasted nuthatch
pygmy nuthatch
pileated woodpecker
hairy woodpecker
yellow-bellied sapsucker

y the third decade after initial cutting, most sites had eloped into multistoried stands. Structural changes in nds probably resulted in reduced numbers of ground lers, including the common flicker, the mountain blue-, and the chipping sparrow. Gains could be expected anopy feeders (solitary vireo, ruby-crowned kinglet, evening grosbeak) and bark feeders (hairy wood-ker, brown creeper, and white-breasted nuthatch). By 3, overstory removal caused the stand structure to e closely resemble that in 1909, except that the trees e largely thrifty poles 60 years old rather than 200 to years old. Birdlife in these stands would probably be h the same as in 1909 except for localized displace-t of the pileated woodpecker or other cavity nesters, the gain of some low-canopy (shrub) feeders.

n moist sites (figs. 16 and 17), stand structure ediately following the 1907-11 logging was similar to r sites except that the tree cover was locally more se. Bird populations were probably comparable to e on other sites. By 1927, a fairly dense but patchy erstory had developed. This probably attracted some ue low-canopy (shrub) feeding species, including the us hummingbird, MacGillivray's warbler, and the warb-vireo. The Empidonex flycatchers would also be cted to these sites. After 1962, logging disturbance lerated establishment and growth of willow, thereby easing feeding opportunities for low-canopy (shrub) ing species. Subsequent growth of conifers and rioration of willow was detrimental to many species ocalized sites.

ie clearcut on private land (fig. 15) probably resulted marked change in bird distribution. The foliage ers and bark feeders would have been displaced, but arge opening was favorable for ground feeders in-ng the common flicker, robin, Townsend's solitaire, ntain bluebird, and chipping sparrow. By 1925, the th of aspen and willow had resulted in a desirable ition of low-canopy (shrub) feeding species. This con-n was particularly desirable for ruffed grouse. The lopment of a single canopy forest largely displaced nd feeders. High-canopy feeders that would find this ition acceptable include the ruby-crowned kinglet, w-rumped warbler, and Townsend's warbler.

GAME

storical narratives suggest that deer and elk were erous between 1805 and 1825 in the Bitterroot Valley vicinity (Koch 1941). Considering habitat preferences, majority of these animals were probably white-tailed Bighorn sheep and mountain goats were locally iful, while moose were scarce.

-game populations were reduced to low levels by julated hunting following settlement. Janson (1967) ts that in 1902 Ranger Than Wilkerson estimated e were only seven elk left in the East Fork" of the root River, an area that formerly supported hun-. Low population levels led to closure of the elk on from 1913 to 1926. Deer populations at the turn of entury were also low.[2]

[2] sonal communication, Fred Hartkorn, Montana Fisheries, Wildlife rks Department, based on a 1950's interview with pioneer settler ord.

An article in the September 12, 1900, edition of the Ravalli County Democrat states that deer were not plentiful and it was a "matter of general information...that no deer wintered in the woods or hills hereabouts...."

After the turn of the century, elk, mule deer, white-tailed deer, and moose populations began to increase in the upper Bitterroot Valley. Excepting white-tailed deer, population highs may have been reached in the mid-1950's. Currently, the Lick Creek area is frequented by these wild ungulates, especially during the winter and spring when forage is available only at lower elevations. The influence of habitat changes on these large mammals is not clearly understood. However, changes in habitat resulting from plant succession appear to be an important contributor to population changes.

In the Rocky Mountains, the winter diet of elk depends on forage availability. Shrubs are the primary forage on the Clearwater River in Idaho where large shrubfields predominate (Leege and Hickey 1977). Where shrubs are a minor vegetal component, grasses usually comprise much of the forage intake during the winter months (Stevens 1966). Historically, the grassy understory in Lick Creek would have been an ideal source of forage for wintering elk. Following settlement, however, it is doubtful that there was sufficient cover for elk because of the open understory and removal of trees by logging. Sparse cover subjects elk to harrassment and allows hunters to be more effective. Beall (1974) found that elk prefer dense conifer stands in which to bed. The development of young conifer stands in Lick Creek and comparable areas appears to have benefited these animals. During the past 30 years, roadbuilding in Lick Creek and other areas negated improvement in cover. Lyon (1979) has shown that elk in western Montana tend to avoid habitat adjacent to traveled forest roads. Road closures in recent years have helped reduce the impact of human disturbance.

Shrubs and trees are an essential part of the diet of mule deer, especially during the winter, when browse may comprise 75 percent or more of the food intake (Hill 1956). Browse was poorly represented in the Lick Creek area in 1909. The only appreciable source appears to have been shiny-leaf ceanothus, a fire-dependent species. Scattered remnant plants indicated this shrub was available in localized areas.

The winter carrying capacity for mule deer increased markedly after logging because of establishment and growth of willow and bitterbrush. Opening of the tree canopy increased sunlight, which stimulated production of remnant plants. Scarification of the soil surface by equipment and slash burning provided mineral soil essential for seedling establishment. Willow seedlings apparently regenerated from windborne seeds (6.5 million/lb [14.3 million/kg]) blown in from as far as several miles away. Soil scarification also favored establishment of bitterbrush seedlings, which have a low rate of survival beneath ponderosa pine where litter has accumulated (Sherman and Chilcote 1972). Seed distribution was likely facilitated by rodent caching (Sanderson 1962; West 1968).

Within the sale area, quality of mule deer habitat varies with time since logging. Browse conditions are most

favorable soon after logging. Browse deteriorates where stand densities have increased and tree canopies have closed.

White-tailed deer are indigenous to the Bitterroot Valley, but their former range appears to have been closely associated with deciduous vegetation in the valley bottom. In the past several decades, white-tailed deer have extended their range into foothills and montane forest comparable to the Lick Creek area where they are occasionally observed. Montana Fish, Wildlife, and Parks Department check station records over the past 5 years show progressive increases in annual harvests of white-tailed deer in the Bitterroot drainages (Firebaugh and others 1979). The extension of white-tailed deer range appears to parallel that noted in central and eastern Montana (Martinka 1968). The reason for this extension may be related to cover requirements. White-tailed deer are more dependent on cover than are mule deer (Keay and Peek 1980). The increased establishment and growth of young conifers in Lick Creek and other areas of the Bitterroot Valley have apparently resulted in a habitat condition suited to the needs of these animals.

At the time of settlement, moose were rarely observed in western Montana, which was reflected in the total closure on moose hunting in 1897. By the 1930's, an occasional moose was seen in Lick Creek and other Bitterroot Valley drainages. Population increases justified permit hunting in 1951.

Photographic evidence suggests that winter moose forage was marginal in the early 1900's because of poor shrub development and the sparcity of young conifers. The winter diet of moose in Montana includes a high intake of willow where this plant is a major component of the vegetation (Knowlton 1960; Dorn 1970). In forests where willow is poorly represented, willow comprises a minor portion of the winter diet (Stevens 1970). Pellet distribution and evidence of browsing in the Lick Creek area suggest that in winter moose feed heavily on willow and bitterbrush. There is also evidence that Douglas-fir is a significant source of winter forage. Stevens (1970) found that Douglas-fir was used when available and may have been a substantial part of the diet in the Gallatin Mountains of south-central Montana. The combined evidence strongly suggests that successional changes have increased moose range and numbers.

The photographic record provides evidence that changes in the forest structure have suited the habitat requirements of several wild ungulates and those small mammals and birds that require cover and a more diversified habitat than existed before settlement.

Benefits to ungulates have not been entirely the result of improved habitat conditions. More aggressive law enforcement and tighter hunting regulations also allowed populations to recover from 1900 lows caused by unregulated hunting.

Habitat suitability for wildlife inhabiting the Lick Creek area has varied with species requirements and successional stage of the vegetation. Because a majority of wildlife species are dependent upon subclimax vegetation, the best management strategy for wildlife provides for periodic renewal of subclimax vegetation. This results in a more diversified habitat that meets the needs of most wildlife species during the successional cycle.

Domestic Livestock

Prior to establishment of the Bitterroot National Forest, livestock were turned out in the spring and allowed to scatter throughout the foothills. After establishment of the Bitterroot Forest Reserve (renamed Bitterroot National Forest in 1898), Lick Creek was included in a cattle allotment that extended from Trapper Creek on the south to Lost Horse Creek on the north, a distance of 14 miles. In 1941, the south boundary of this allotment was moved north to Bunkhouse Creek and the name changed to the Lost Horse-Bunkhouse Allotment. Currently, this allotment includes 16,076 acres, of which 4,123 acres are primary range. Domestic sheep (numbers unknown) were permitted until 1912. In 1939 (earliest record) 258 cattle were permitted. The numbers of cattle grazed have varied from a high of 364 in 1941 to a low of 93 in 1956. Because of permittee preference, there has been no grazing since 1975.

The Lost Horse Creek-Trapper C & H Allotment has been considered marginal cattle range because a large percentage is steep and covered by conifers. Use has been mostly confined to creek bottoms and adjacent openings in gentle terrain, which offer modest amounts of forage.

There is little information available on the influence of past grazing. Range observations in 1939 indicated that the allotment, other than some recently purchased private land, was in a "properly grazed condition, excepting along ridgetops which were slightly overgrazed." The Lick Creek photo series suggests that livestock use of the study area was negligible at the localities pictured and in the years the photos were taken. Plant parts are intact except for the 1927 scenes, which were made in the fall after curing. It is known that sheep use was heavy in 1912, the last year these animals were permitted to graze. The sites would not be preferred by cattle because of excessive slope, low grass production, or excessive distance from water. A 1964 Range Management Plan indicates that conifer reproduction has been satisfactory in spite of grazing.

The primary influence of livestock grazing has been the reduction of fine fuels in large openings, on ridges, and along drainages. In the past, this has reduced the potential for spread of wildfire. However, nonuse on this allotment is resulting in yearly production of fine fuels that would allow wildfire to carry through openings and across bottomlands given ignition and extreme burning conditions.

Esthetics

The Lick Creek photo series was evaluated for esthetic qualities by Robert E. Benson, research forester, Forest Sciences Laboratory, Missoula, Mont. These photographs were compared to similar landscapes that have been extensively evaluated by viewer panels, and the panels' probable reaction was applied.

The open parklike appearance of most scenes following rvest in 1907-11 was rated high because of the uniform aracter of the landscape. Slash piles in some scenes, wever, detracted from the view. Understory develop-ent between 1909 and 1952 resulted in a decline in enic quality because of obstruction of views. Logging in 1950's and 1960's provided an opportunity for more tant views, but accumulative slash detracted from the w. Scenic quality had improved by 1979 as a result of sh deterioration and screening of slash by young trees. e growth should improve scenic quality until stands se and views are obstructed.

Clearcutting, accompanied by fairly large amounts of attered slash comparable to figure 15, would likely be nsidered obtrusive by viewers. "Thickening up" of the w timber stand following 1909 enhanced the scenic ality, but this growth became so dense that visual ality was substantially reduced.

The visual analysis suggests that the 1909 scenes were re scenic than those of later years. Tree growth ween 1909 and 1952 obstructed views and resulted in uced scenic quality. Logging improved viewing dis-ce, but contributed to slash accumulations that the blic dislikes. Deterioration of slash and screening by growth of young conifers during recent years has proved scenic quality, but views will be impaired and enic quality will decline as succession advances. The enic quality of stands comparable to Lick Creek will eriorate if stands are not kept open by logging. An ceptable level of scenic quality can be achieved by od slash cleanup, facilitated by use of prescribed fire.

MMARY AND CONCLUSIONS

The Lick Creek photopoints present a rare opportunity witness forest succession in managed ponderosa pine Douglas-fir stands through 70 years. The photo-phs, accounts of early forest conditions, and fire tory studies show that prior to the advent of fire sup-ssion, lower elevation forests of the Bitterroot Valley e made up of well-stocked stands of large ponderosa es having open understories. Surface fires swept ough these stands at intervals of between 3 and 30 rs, consuming most of the grass, shrubs, and tree eneration, but causing little damage to overstory trees. 1907-11 logging operations and subsequent lack of und fires dramatically changed the patterns of plant cession at Lick Creek. Large quantities of overstory es were felled, creating sizable openings. Logs were dded and slash was burned in piles, locally scraping or consuming surface vegetation, pine needle litter, humus, and exposing mineral soil. The photo uences covering the next 40 years show that tall ubs (especially Scouler willow) and tree regeneration ame established in direct proportion to the amount of nd opening and ground disturbance. The response of shrubs and tree regeneration was most vigorous on moist habitat types. The transition shown on the st habitat types begins with stands dominated by e ponderosa pines and some Douglas-fir. These had n understories, with ground cover composed primarily ow shrubs and pinegrass. After the 1907-11 logging and subsequent fire suppression, vigorous pole/tall shrub communities of Douglas-fir, ponderosa pine, and Scouler willow developed, with a low shrub and pinegrass ground cover beneath. Mechanical thinning of the pole stands since 1950 has kept the willow and undergrowth from becoming badly suppressed.

On dry habitat types, the original dry grassland type of undergrowth was replaced within a few decades by conifers and shrubs, including antelope bitterbrush. Dense pole stands developed on much of the area 30 to 40 years after logging, tall shrubs began to be shaded out, and undergrowth, in general, became sparse. After thinning of the pole stands and removal of the remaining old-growth pine in the 1950's and 1960's, however, tall shrubs and other undergrowth became more dense. Today, after thinning, the remaining pole-size conifers generally show good vigor and growth. Composition has shifted toward mixed stands of ponderosa pine and Douglas-fir. With continued light partial cuttings, Douglas-fir will probably dominate many of the sites. Cuttings that create larger openings and discriminate against Douglas-fir, and the introduction of prescribed underburns, will be needed to maintain ponderosa pine in a dominant position.

Partial cutting practices on the Lick Creek area were largely successful in meeting timber management objectives. Although timber goals were not well defined in the old records, managers aimed at maintaining reasonable growth for subsequent harvests, at regenerating the site, and at maintaining ponderosa pine as a major component of the stand. The latter goal turned out to be the most challenging. Prior to 1909, light loading of downed woody material and sparsity of ladder fuels precluded the development of crown fires. Partial cutting and fire exclusion in the ponderosa pine type resulted in increased downed woody material and ladder fuels. The major fuels change was the development of live ladder fuels, which increased the susceptibility of the original stand to crown fire. The potential for crown fire was highest in the early 1950's prior to logging and thinning. Overstory removal and thinning in the 1950's and 1960's reduced the potential of crowning in some localities, but establishment of ladder fuels in recent years is increasing this potential. If future crown fires are to be averted, logging slash should be treated and ladder fuels thinned periodically. The judicious use of underburning at appropriate intervals (25 to 30 years) has the potential of reducing both ground and ladder fuels as well as achieving benefits for wildlife and recreation

Considering past vegetative trends and current management direction, which emphasizes timber production, the best wildlife management coordination strategy is one that favors continued development of the conifer overstory while allowing regeneration and growth of shrubs and herbs. The primary tool to accomplish this objective is periodic thinning and selective logging. Underburning is desirable in localities where thinning removes the potential for crown fires. Good response from willow seedlings could be expected on sites where burning is thorough enough to expose mineral soil. Regeneration from suckers would occur where willows are well distributed and in need of rejuvenation. In some localities, where fuels are

light, an underburn would rejuvenate decadent bitterbrush. Spring or fall ignitions initiate sprouting and establishment of new plants from seed. The scenic quality of stands comparable to Lick Creek will deteriorate if stands are not kept open by logging or periodic underburning. Acceptable scenic quality can be achieved by good slash cleanup.

The massive change in forest conditions in the Lick Creek Study area has also taken place in similar habitat types in the Bitterroot Valley and western Montana. Without periodic burning or logging this forest type develops into dense tree stands, a condition detrimental to many important forest values. The combined evidence demonstrates that, carefully planned and executed, logging and burning of slash can enhance productivity and esthetic quality of the forests.

All of the silvicultural systems described in this paper would be useful in this forest type when coordinated with stand composition, vigor, and site, disease, and insect conditions. Defining the long-term objectives is the primary key to choice of silvicultural prescriptions. Once the management objectives are set, these observations of timber and other resources on Lick Creek provide a basis for management decisions in the ponderosa pine/ Douglas-fir forests of the Northern Rockies.

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APPENDIX I

Wildlife Species Discussed in Text

Big Game

mule deer	*Odocoileus hemionus*
white-tailed deer	*Odocoileus virginianus*
elk	*Cervus elaphus nelsonii*
moose	*Alces alces*
bighorn sheep	*Ovis canadensis*
mountain goat	*Oreamnos americanus*

Small Mammals

ground squirrels	*Spermophilus* spp.
golden-mantled ground squirrel	*Spermophilus lateralis*
northern pocket gopher	*Thomomys talpoides*
deer mouse	*Peromyscus maniculatus*
voles	*Clethrionomys* spp. and *Microtus* spp.
shrews	*Sorex* spp.
chipmunks	*Eutamias* spp.
red squirrel	*Tamiasciurus hudsonicus*
northern flying squirrel	*Glaucomys sabrinus*
snowshoe hare	*Lepus americanus*
mountain cottontail	*Sylvilagus auduboni*
porcupine	*Erethizon dorsatum*

Carnivores

bobcat	*Lynx rutus*
coyote	*Canis latrans*
longtail weasel	*Mustela frenata*

Raptors

Cooper's hawk	*Accipiter cooperii*
sharp-shinned hawk	*Accipiter striatus*
great horned owl	*Bubo virginianus*

Birds

blue grouse	*Dendragapus obscurus*
ruffed grouse	*Bonasa umbellus*
rufous hummingbird	*Selasphorus rufus*
common flicker	*Colaptes auratus*
pileated woodpecker	*Dryocopus pileatus*
hairy woodpecker	*Dryocopus villosus*
yellow-bellied sapsucker	*Sphyrapius varius*
olive-sided flycatcher	*Nuttallornis borealis*
mountain chickadee	*Parus atricapillus*
white-breasted nuthatch	*Sitta carolinensis*
red-breasted nuthatch	*Sitta canadensis*
pygmy nuthatch	*Sitta pygmaeae*
brown creeper	*Certhia familiaris*
Townsend's solitaire	*Myadestes townsendi*
robin	*Turdus migratorius*
Swainson's thrush	*Hylociachla ustulata*
mountain bluebird	*Sialia currucoides*
ruby-crowned kinglet	*Regulus calendula*
warbling vireo	*Vireo gilvus*
solitary vireo	*Vireo solitarius*
yellow-rumped warbler	*Dendrocia coronata*
Townsend's warbler	*Dendrocia townsendi*
MacGillivray's warbler	*Oporornis agilis*
western tanager	*Piranga ludoviciana*
evening grosbeak	*Hesperiphona vespertina*
Cassin's finch	*Carpodocus cassinii*
pine siskin	*Spinus pinus*
red crossbill	*Loxia curvirostra*
dark-eyed junco	*Junco hyemalis*
chipping sparrow	*Spizella arborea*

APPENDIX II

Trees, Shrubs, and Herbs Found on Lick Creek Study Area

Trees

ponderosa pine	*Pinus ponderosa*
Douglas-fir	*Pseudotsuga menziesii*
grand fir	*Abies grandis*
Engelmann spruce	*Picea engelmannii*

Shrubs and Low Woody Plants

snowberry	*Symphoricarpos albus*
dwarf huckleberry	*Vaccinium caespitosum*
blue huckleberry	*Vaccinium globulare*
kinnikinnick	*Arctostaphylos uva-ursi*
white spiraea	*Spiraea betulifolia*
Scouler willow	*Salix scouleriana*
antelope bitterbrush	*Purshia tridentata*
shiny-leaf ceanothus	*Ceanothus velutinus*

Grasses and Forbs

pinegrass	*Calamagrostis rubescens*
elk sedge	*Carex geyeri*
bluebunch wheatgrass	*Agropyron spicatum*
Idaho fescue	*Festuca idahoensis*
Arrowleaf balsamroot	*Balsamorhiza sagittata*

Gruell, George E.; Schmidt, Wyman C.; Arno, Stephen F.; Reich, William J. Seventy years of vegetal change in a managed ponderosa pine forest in western Montana—implications for resource management. Gen. Tech. Rep. INT-130. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1982. 42 p.

Interprets changes in forest vegetation resulting from timber harvests and a marked reduction in the occurrence of fire. A series of photographs at about 10-year intervals, starting in 1909, provide the basis for describing how a ponderosa pine forest has changed since settlement. The reasons for changes and implications on wildlife, timber, fuels, esthetics, and livestock grazing are discussed.

KEYWORDS: ponderosa pine, forest succession, fire, timber, wildlife, photographic record

The Intermountain Station, headquarted in Ogden, Utah, is one of eight regional experiment stations charged with providing scientific knowledge to help resource managers meet human needs and protect forest and range ecosystems.

The Intermountain Station includes the States of Montana, Idaho, Utah, Nevada, and western Wyoming. About 231 million acres, or 85 percent, of the land area in the Station territory are classified as forest and rangeland. These lands include grasslands, deserts, shrublands, alpine areas, and well-stocked forests. They supply fiber for forest industries; minerals for energy and industrial development; and water for domestic and industrial consumption. They also provide recreation opportunities for millions of visitors each year.

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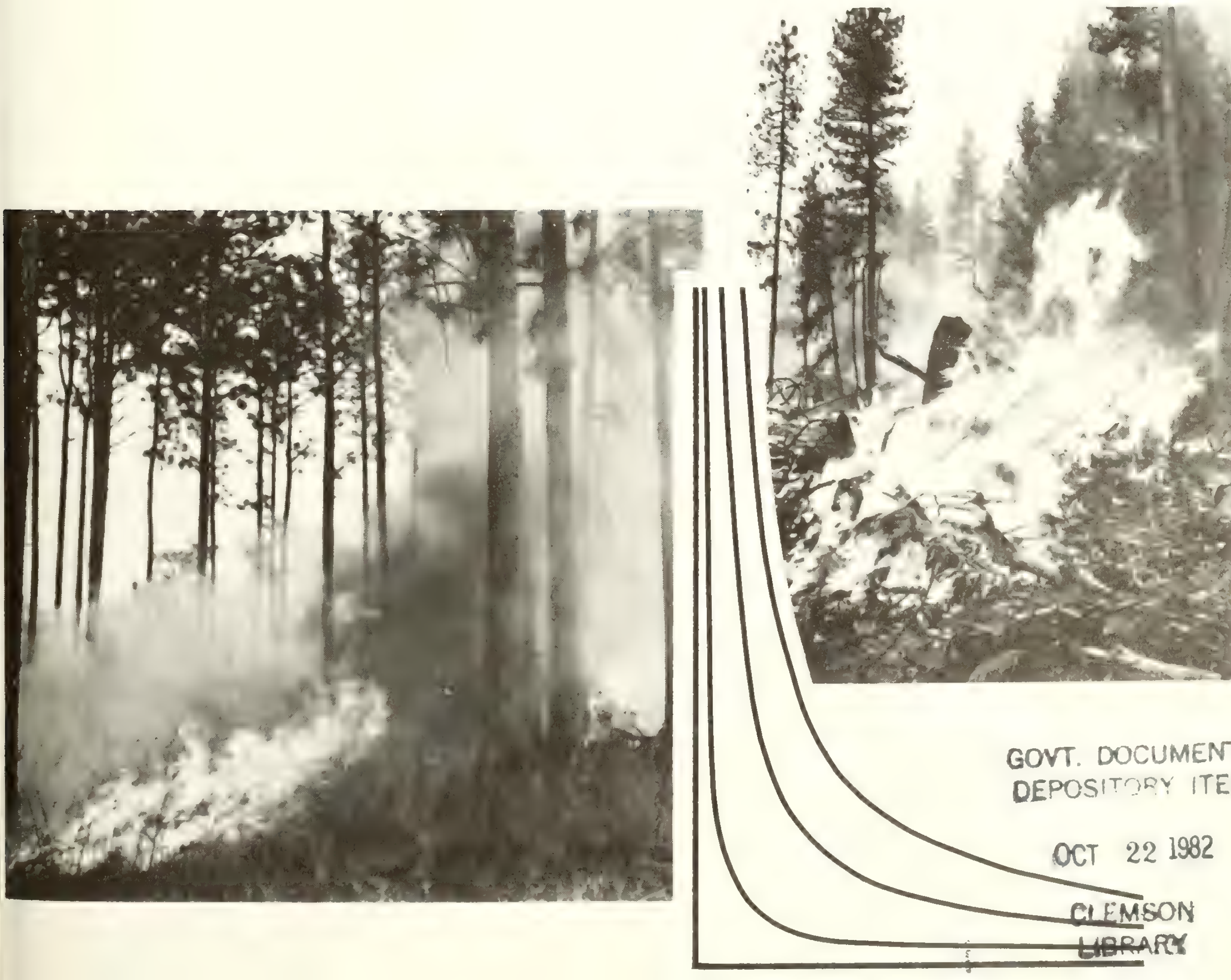
**Intermountain
Forest and Range
Experiment Station
Ogden, UT 84401**

General Technical
Report INT-131

September 1982

Charts for Interpreting Wildland Fire Behavior Characteristics

**Patricia L. Andrews
and Richard C. Rothermel**



THE AUTHORS

PATRICIA L. ANDREWS is a mathematician stationed at the Northern Forest Fire Laboratory in Missoula, Mont. She received her B.A. in mathematics and chemistry from Eastern Montana College, Billings, in 1970, and her M.A. in mathematics and computer science in 1973 from the University of Montana, Missoula. She has been employed at the Northern Forest Fire Laboratory since 1973.

RICHARD C. ROTHERMEL is a research engineer stationed at the Northern Forest Fire Laboratory in Missoula, Mont. Rothermel received his B.S. degree in aeronautical engineering at the University of Washington, Seattle, in 1953. He served in the U.S. Air Force as a special weapons aircraft development officer from 1953-55. Upon his discharge he was employed at Douglas Aircraft Company as a designer and troubleshooter in the Armament Group. From 1957 to 1961 Rothermel was employed by General Electric Co. in the aircraft nuclear propulsion department at the National Reactor Testing Station in Idaho. In 1961, Rothermel joined the Northern Forest Fire Laboratory where he has been engaged in research on the mechanisms of fire spread. He received his master's degree in mechanical engineering at the University of Colorado, Fort Collins, in 1971. He was project leader of the Fire Fundamentals research work unit from 1966 until 1979, and is currently project leader of the Fire Behavior research work unit at the fire laboratory.

RESEARCH SUMMARY

The fire characteristics chart is proposed as a graphical method of presenting two primary characteristics of fire behavior: spread rate and intensity. Its primary use is communicating and interpreting either site-specific predictions of fire behavior or National Fire-Danger Rating System (NFDRS) indexes and components. Rate of spread, heat per unit area, flame length, and fireline intensity are plotted on a fire behavior chart. Spread component, energy release component, and burning index are plotted on an NFDRS chart.

Specific examples illustrate use of a fire characteristics chart in conjunction with fire prescriptions, fire behavior forecasts, fire management plans, and briefings.

The equations used in creating the charts are given; and a method of obtaining heat per unit area from fire behavior nomograms is illustrated.

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FIRE CHARACTERISTICS CHARTS

A fire characteristics chart is a graph that illustrates the two primary characteristics of fire behavior—spread rate and intensity. Overall fire severity, as well as the character of the fire, can be inferred from the location of a point representing the fire on the chart. The chart is mainly useful as a communication aid. The fire characteristics chart can be used for site-specific predictions of fire behavior (fig. 1) or for National Fire-Danger Rating System (NFDRS) indexes and components (fig. 2).

There is a pressing need for analysis of fire behavior and a clear understanding of the analysis at all levels of management. Fire policy on National Forests has shifted emphasis from fire control to fire management. In addition to traditional fire control and use activities, a successful fire manager must also evaluate alternative fire management strategies in relation to land and resource management objectives. A vital part of this process is communication with other resource specialists who may not be familiar with the National Fire-Danger Rating System or methods for predicting site-specific fire behavior. Quantitative descriptors of fire behavior are becoming more widely used due to the prevalence of automated systems (Rothermel 1980). The hand-held TI-59 calculator with a Fire Danger/Fire Behavior Custom Read Only Memory (CROM) is an example of technology that is reaching every level of fire manager—from dispatchers to regional planners (Burgan 1980). Fire characteristics charts allow graphic presentation of quantitative fire behavior information in a form that is readily understood.

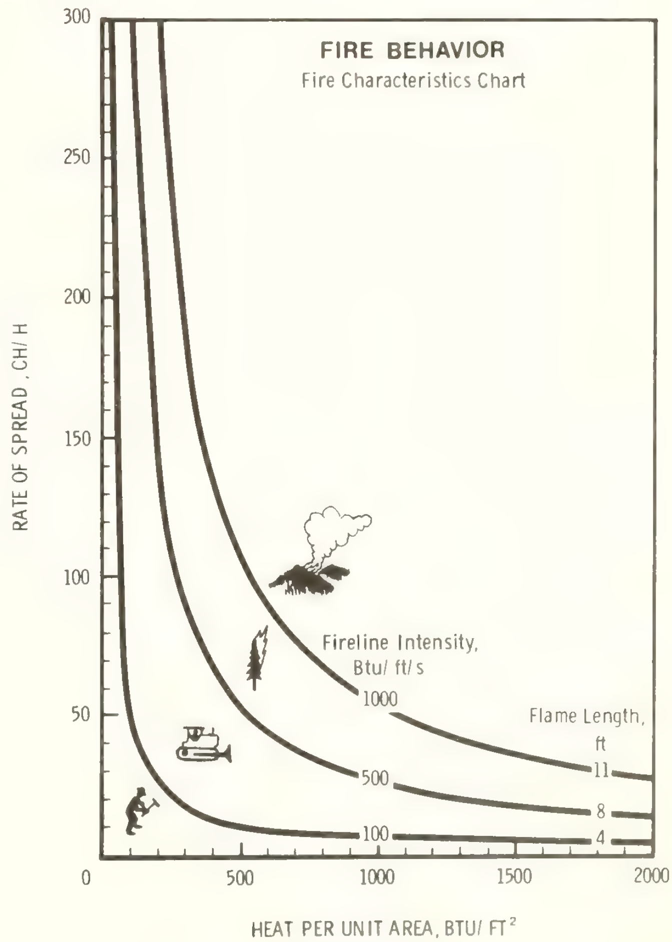

Figure 1.—Fire behavior fire characteristics chart.

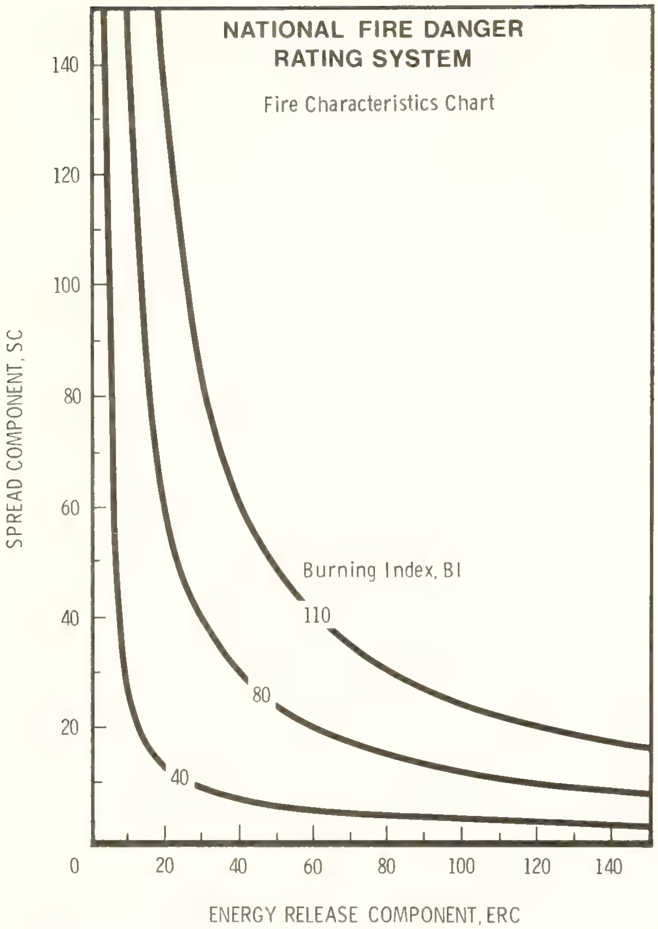

Figure 2.—National Fire-Danger Rating System (NFDRS) fire characteristics chart.

FIRE BEHAVIOR CHARTS

The values that are plotted on the fire behavior charts are based on a mathematical model for predicting fire spread in wildland fuels (Rothermel 1972). Calculations are made using nomograms (Albini 1976a), computer (Albini 1976b), or calculator (Burgan 1979). The model estimates actual fire behavior from specific descriptions of fuel type, fuel moisture, topography, and wind. The four descriptors of fire behavior that are plotted as a single point on the chart are:

1. Rate of spread (chains/hour), the forward rate of spread at the head of a surface fire.

2. Heat per unit area (Btu/ft^2), a measure of the amount of heat that is released by a square foot of fuel while the flaming zone of the fire is in that area. (Procedures for obtaining this value from nomograms and the equation for modifying existing computer programs are given in appendix A.)

3. Flame length (feet), the length of the flame at the head of the fire measured from the middle of the combustion zone to the average position of the flame tip. Flame length is determined by the rate of spread and the heat per unit area of the fire.

4. Fireline intensity (Btu/ft/s), the amount of heat released per second by a foot-wide slice of the flaming combustion zone (Byram 1959). This value has been directly related to flame length, an observable characteristic of fire behavior. Fireline intensity is indicative of the heat that would be experienced by a person working near the fire.

Flame length and fireline intensity can be interpreted in terms of suppression capabilities as shown in table 1. The curved lines on the fire behavior chart define the areas of interpretations shown in table 1. The interpretations range from fires being easily controlled by hand crews, to fire o ich equipment can be effective, to fires on whicl trol effort at the head will be ineffective.

As an illustration of how the fire behavior chart works, the fire behavior prediction values listed in table 2 are plotted in figure 3. These predictions are for fires in three fuel types burning under the same wind, slope, and fuel moisture conditions. The fuel types were chosen from the 13 stylized fire behavior fuel models (Anderson 1982). Fuel model 1 represents continuous stands of arid western grass; fuel model 10, litter and understory of a timber stand with heavy accumulations of deadfall; and fuel model 8, short-needle litter.

The differences among the characteristics of the fires in these three fuel types are readily apparent from their

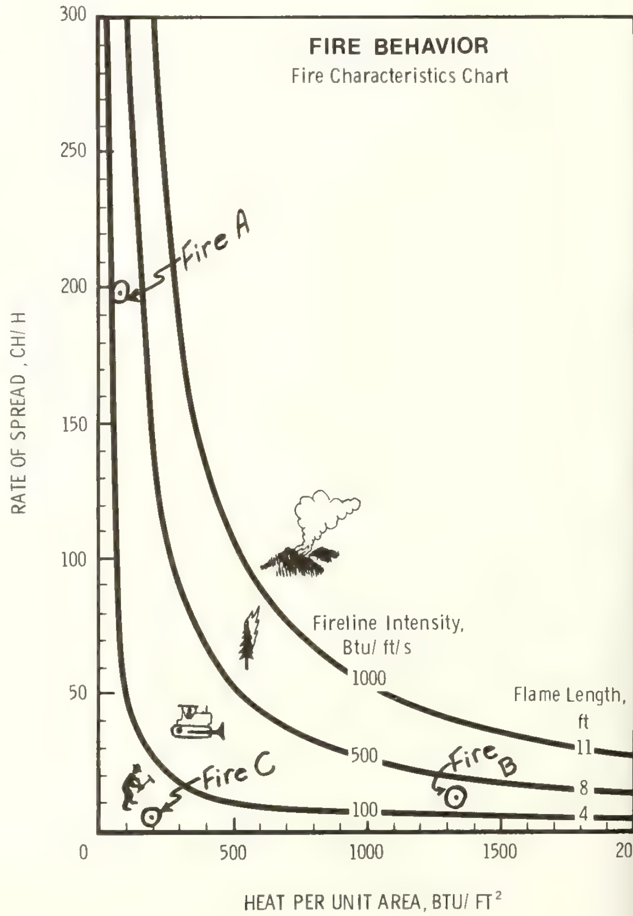

Figure 3.—Fire behavior predictions from table 2 plotted on a fire behavior chart.

le 1.—Fire suppression interpretations of flame length and fireline intensity

Flame length	Fireline intensity	Interpretation
Feet	*Btu/ft/s*	
< 4	< 100	Fire can generally be attacked at the head or flanks by persons using handtools. Handline should hold the fire.
4-8	100-500	Fires are too intense for direct attack on the head by persons using handtools. Handline cannot be relied on to hold fire. Equipment such as plows, dozers, pumpers, and retardant aircraft can be effective.
8-11	500-1,000	Fires may present serious control problems—torching out, crowning, and spotting. Control efforts at the fire head will probably be ineffective.
> 11	> 1,000	Crowning, spotting, and major fire runs are probable. Control efforts at head of fire are ineffective.

le 2.—Fire behavior predictions for specific fuel, moisture, wind, and slope conditions

Descriptors	Fire A	Fire B	Fire C
l and environmental conditions:			
Fuel model	1	10	8
Dead fuel moisture, percent	5	5	5
Live fuel moisture, percent	100	100	100
Midflame windspeed, mi/h	7	7	7
Slope, percent	10	10	10
behavior predictions:			
Rate of spread, chains/h	197	14	4
Heat per unit area, Btu/ft^2	92	1,330	200
Fireline intensity, Btu/ft/s	333	344	13
Flame length, ft	7	7	1

ement on the chart. Notice that flame length and ne intensity are essentially the same for fires A and re A is very fast spreading and has a low heat per area. On the other hand, fire B is slow spreading, has a high heat per unit area. Both fires A and B predicted to be too intense for direct attack at the by persons using handtools (table 1), but this ee of severity is caused by fires of very different acter.

e C occurs under the same wind, slope, and fuel ture conditions as fires A and B. But the handline ld easily hold fire C, whereas plows, dozers, pers, or retardant would probably be required on A and B. Notice that the character of these three can be determined by a glance at the chart. The information is on table 2, but is not as easily preted.

general, fires with a high rate of spread and low per unit area are plotted near the upper end of the al axis, whereas fires with low rates of spread and heat per unit area fall to the right, near the hori- l axis. Fires with both high spread rate and high s of heat per unit area will lie in the center of the far from the origin. The overall severity of the shown by increasing flame length and fireline sity curves.

Although a point on the chart represents the charac- teristics of a fire, a circle around the point would more appropriately indicate the probable range of fire behavior. The numbers used to characterize fire behavior are a best estimate based on a mathematical model, and are subject to the assumptions and limita- tions of that model as described by Rothermel (1972) and Albini (1976a). In addition, fire is inherently vari- able and cannot be uniquely described over an area. The circle around a point becomes larger with more nonuniform fuels, more variable wind, and increasing fire severity. There are no simple techniques for esti- mating the range of fire behavior characteristics caused by nonuniformities at this time.

Because several fire behavior characteristics are plotted as a single point and because it is easier to interpret illustrations than arrays of numbers, the fire behavior chart lends itself to many applications. The chart can be used to illustrate the fire management activities and associated fire characteristics listed below:

Project fires

- Expected fire behavior given as written narrative in the fire behavior forecast.
- Expected change in fire behavior that may ac- company a forecasted weather change.
- Level of fire behavior considered in an escaped

fire analysis.
- Expected change in fire behavior with a change in fuel type.

Prescribed fire
- Fire characteristics required to achieve specific burn objectives.
- Fire behavior expected under a range of weather conditions.
- Behavior of an escaped fire.
- Conditions that will require using ignition patterns to draw the fire and produce the desired intensity.
- Behavior of strip fires—bracketed by plotting the behavior of a backing fire and a free-burning head fire.

Long-range planning
- Variation of fire behavior between planning units under the same weather conditions.
- Effect of a change in fuel type on fire behavior.

Application of Fire Behavior Charts

EXAMPLE: FIRE PRESCRIPTIONS

Successful prescribed burning requires planning. Fischer (1978) proposes a four-point fire use plan and report: treatment area and objectives, fire prescription, burning plan, and report. The fire prescription portion includes a section on fire behavior and associated environmental conditions desired to meet burn objectives.

Increasingly specific fire management objectives have created a need for more quantitative descriptions of fire behavior. Rate of spread described as fast or slow, or fire intensity as hot or cool, is often not adequate. The four values plotted on the fire characteristics chart describe aspects of fire behavior that are important in both fire control and fire effects considerations. Flame length and fireline intensity are directly related to the effectiveness of control forces. Many prescribed burns are conducted under conditions that produce flame lengths less than 3 feet. Rothermel and Deeming (1980) have suggested that fireline intensity be correlated to fire effects in the flames or in the convection column, and heat per unit area be correlated to fire effects near the base of the fire in the duff and litter. Fire behavior can be quantified on a fire characteristic chart without dwelling on tables and numbers. An example of a section of a fire use plan and report and the associated fire behavior chart are shown in figures 4 and 5.

Part 2 — Fire Prescription

2.1 Treatment Specifications

2.11 Desired Accomplishment

— Kill shrubs and trees <5" D.B.H. without killing the overstory of western larch.

— Expose mineral soils over 60% of the area

— Reduce duff by 86%.

2.12 Desired Fire Behavior

— The flame length must be less than 4 feet to ensure that less than 60% of the crowns will be scorched, therefore allowing the larch to survive.

— Due to discontinuity of fuels, a head fire with a flame length of at least 2 feet is required to achieve a uniform burn pattern

— The flame length should be less than 4 feet to reduce the risk of torching and spot fires. The burn area is within a mile of some 2-year old logging slash. If a spot fire occurs in the slash, it will require pumpers and possibly retardant for control.

— Under the burning conditions that are required to meet desired duff reduction objectives, a free-burning, forward-spreading fire would make torching, crowning, and spotting probable. Strip headfires will be used to keep the fire behavior within the required range.

2.13 Required Environmental Conditions

Relative Humidity	— 20-30%
Temperature	— 70-80 F
Windspeed (midflame)	— N-NW — 3-7 mph
1-H Fuel Moisture	— 10-14%
10-H Fuel Moisture	— 12-14%
Live Fuel Moisture	— 75-125%
Duff Moisture	— 50%

Figure 4.—The fire prescription part of a fire use plan and report.

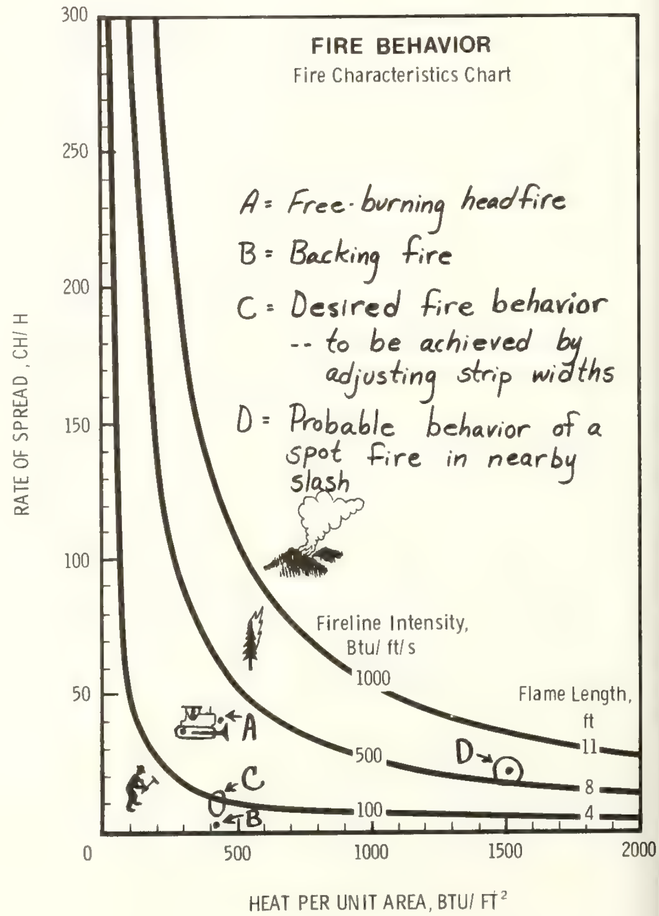

Figure 5.—Use of a fire characteristics chart to illustrate the desired fire behavior portion of the prescription given in figure 4.

EXAMPLE: FIRE BEHAVIOR FORECAST

A fire behavior officer (FBO) is normally part of an overhead team on a project fire. His duties include identifying critical fire behavior conditions and projecting fire size. He prepares a fire behavior forecast which includes a written narrative describing potential fire behavior. This is done for briefing the fire overhead team and is revised whenever conditions warrant a new appraisal of fire behavior. One of the tools the FBO uses in his job is the fire behavior model in the form of nomograms or the TI-59 calculator. The numerical output from the model must be interpreted by the FBO before it is communicated. In addition to the narrative fire behavior forecast and a map indicating expected fire growth, a fire characteristics chart can be used in the oral briefing to illustrate potential fire behavior for different sectors of the fire. A fire behavior forecast and the associated fire characteristics chart are shown in figures 6 and 7.

FIRE BEHAVIOR FORECAST NO. ________

NAME OF FIRE: ________________ **PREDICTION FOR:** ____Day____ **SHIFT**

FOREST: ________________ **SHIFT DATE:** ________

TIME AND DATE FORECAST ISSUED: ____0900____ **SIGNED:** ________________
FIRE BEHAVIOR OFFICER

WEATHER SUMMARY RED FLAG ALERT SEE ATTACHED SPOT FORECAST.

Note Terrain channeling of the general wind up the river will produce up-canyon winds of 5 to 10 mi/h along the lower slopes and 10 to 15 mi/h along upper slopes by early afternoon.

FIRE BEHAVIOR

GENERAL: Fire will be relatively inactive until the inversion breaks, about 1200. Fire activity will increase sharply at that time with fire spread mainly up-canyon to the southwest. Some torching will occur where fuel concentrations exist with short range spotting possible.

SPECIFIC:

SECTOR A. Fire spread will be relatively low on this sector (3 chains per hour), but rolling firebrands will be a problem, especially in the small draws to the south. Roll into unburned fuels will result in upslope runs with some torching and short range spotting.

SECTOR B. This will be a hot sector on the fire today. Direct attack with hand crews will be marginal until 1100 and impossible after the inversion breaks. Roll and spotting will cause short runs to the ridge, especially in the small draws to the south.

SECTOR C. The fire will back slowly down canyon against the wind. Rolling material may cause some problems, but this will be the coolest sector on the fire. Conditions will be good for direct attack to succeed.

AIR OPERATIONS: Strong inversion will limit air operations until about noon. Any thunderstorms that occur later in the day will produce turbulent flying conditions.

SAFETY: Crews should be alert to the danger of roll igniting fuels below them on steep slopes.
If thunderstorms enter the fire area, be alert for the possibility of erratic fire behavior from downdraft winds. A weather watch has been established to give warning of approaching thunderstorms.

Figure 6.—Fire behavior forecast.

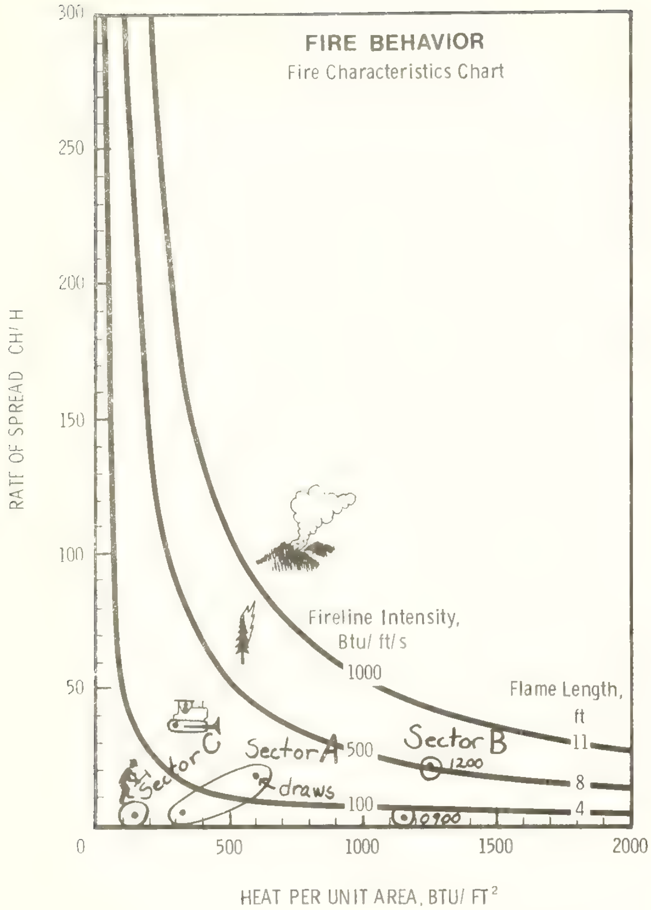

Figure 7.—Use of a fire characteristics chart to illustrate the fire behavior given in the fire behavior forecast in figure 6.

NATIONAL FIRE-DANGER RATING SYSTEM CHARTS

The National Fire-Danger Rating System (NFDRS) (Deeming and others 1977) is used throughout the country for fire management planning. Most users obtain daily ratings using a centralized computer (Helfman and others 1980); some use nomograms (Burgan and others 1977), or the TI-59 calculator with a fire danger/fire behavior CROM (Burgan 1979). Management guidelines are often based on indexes obtained by processing historical weather records through standard computer programs (Main and others in press; Bradshaw and Fischer 1981a, 1981b).

The NFDRS is comprised of many components and indexes related to fire occurrence, fire behavior, and fire suppression. The following items can be plotted on a fire characteristics chart similar to the one used for site-specific fire behavior estimation:

1. Spread component (SC)—related to rate of fire spread.

2. Energy release component (ERC)—related to energy or heat that will be released in a passing fire front.

3. Burning index (BI)—related to the magnitude of the fire containment problem. The burning index is derived from the spread component and the energy release component.

The three values are related to the corresponding values on the fire behavior-fire characteristics chart. Procedures used to calculate spread component, energy release component, and burning index were in fact derived from the equations for rate of spread, heat per unit area, and flame length. NFDRS indexes and components are designed to give broad area rating of fire potential and are not meant to predict actual site-specific fire behavior. The indexes are based on fuel models that describe large areas and on weather taken at a specific location once per day.

Because NFDRS components and indexes are relative indicators of fire danger, a value is meaningful only when it is compared with other values. Seasonal plots illustrated in figure 8 help one make such comparisons. An index value can be readily related to previous values in the season or, if plots are overlaid, to those from other seasons. As can be seen in figure 8, ERC had climbed to the highest point thus far that season by August 3, and did not change on August 4. However, SC for August 4 was four times as high as that on August 3, and BI nearly doubled from August 3 to August 4. Notice also that on October 3, BI was approximately the same as it had been on August 3, but SC was much higher and ERC much lower.

The fire characteristics chart offers another means of interpreting SC, ERC, and BI in terms of potential fire behavior. The values for August 3, August 4, and October 3 are plotted on the NFDRS chart in figure 9. The curved lines on the fire characteristics chart correspond to the horizonal lines on the seasonal plot of burning index. Notice how the character of fire danger on all 3 days is readily apparent.

The seasonal plots and the fire characteristics chart illustrate different aspects of SC, ERC, and BI. A seasonal plot reflects the change of conditions in a component or index over time, whereas the NFDRS chart is best suited for illustrating the relationship among all three values at a particular time.

NFDRS calculations are normally done on a day-to-day basis using standard weather observations as input. The TI-59 calculator with a fire danger/fire behavior CROM allows another option: fuel moisture can be entered directly in lieu of weather input. This allows the user to look at situations that are not based on the seasonal trend. For example, "under the same conditions, how does the fire danger change with a change of fuel models?" or "what would the fire danger be if the moisture content of the large fuels were 3 percent less?" The NFDRS chart is an ideal way of illustrating the change in fire danger due to a specific change in conditions.

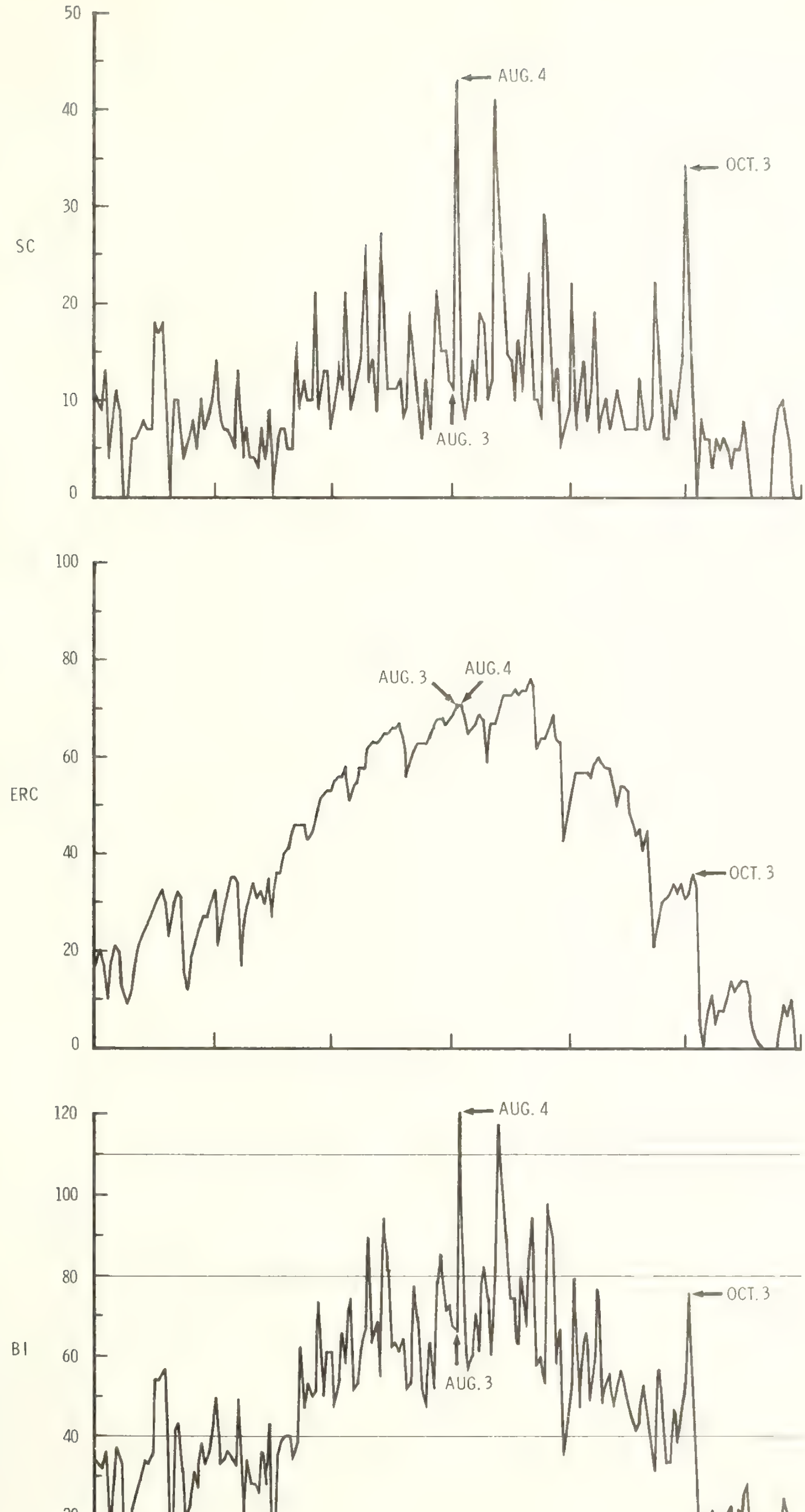

Figure 8.—Seasonal plots of spread component (SC), energy release component (ERC), and burning index (BI).

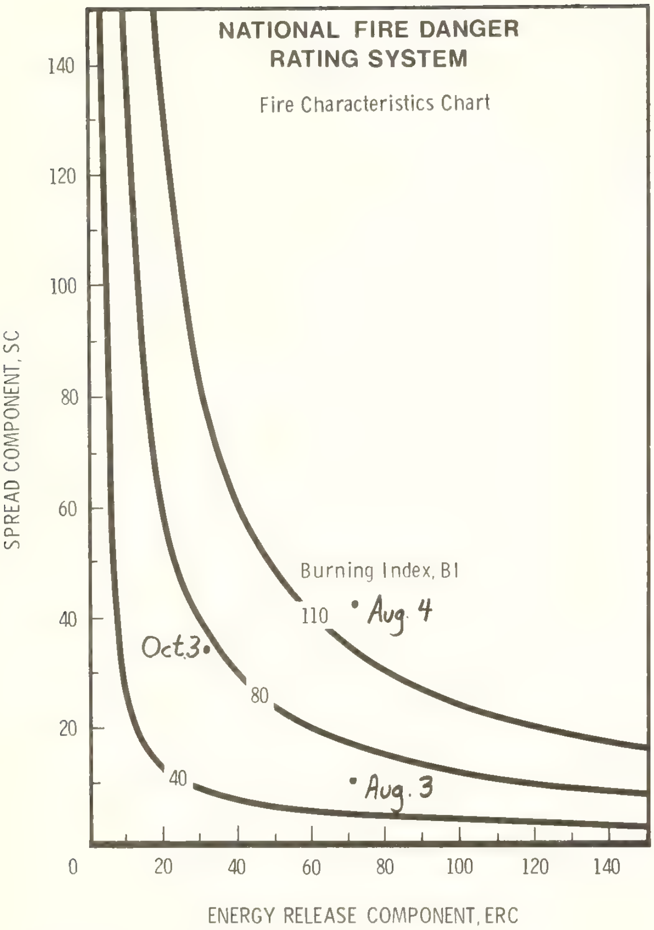

Figure 9.—SC, ERC, and BI for August 3, August 4, and October 3 from the seasonal plots in figure 8 plotted on an NFDRS chart.

A review of each index and the relationship between them will clarify the use of the NFDRS chart. Spread component is related to the rate of fire spread and is strongly affected by windspeed; SC can therefore have wide daily fluctuations. On the other hand, windspeed has no effect on energy release component. ERC is related to the energy released in the flaming zone and mainly reflects changes in fuel moisture. Because ERC is not affected by wind, it shows a more definite seasonal trend than either SC or BI. Burning index is derived from the spread and energy release components and has the same underlying trend as ERC with the daily fluctuations of SC imposed on it. Depending on the type of management decisions to be made, SC, ERC, BI, or a combination of these values can be used.

Application of NFDRS Charts

EXAMPLE: FIRE MANAGEMENT PLANS

USDA Forest Service fire management policy currently recognizes two categories of fires on its lands: wildfires and prescribed fires. Every wildfire requires an appropriate suppression response. Every prescribed fire is to be conducted in compliance with an approved plan. Unplanned ignitions can be allowed to burn as prescribed fires as long as they meet criteria established in approved fire prescriptions.

The Troy Ranger District in northwestern Montana prepared a fire management plan that covered the entire district. The plan was approved in early 1979, and several unplanned ignitions were used as prescribed fires that summer. A fire management prescription covers each of five fire management categories. Figure 10 is a flowchart for managing fires on big-game spring and winter ranges on operational fire management areas. Among the conditions that must be satisfied for a fire to be allowed to burn in these areas are limits on burning index and energy release component. The shaded area of the NFDRS chart in figure 11 illustrates these limits. If the plotted points from the last 4 days fall to the left of the vertical line where ERC = 30, and if the current day's point and the point forecasted for the next day fall in the smaller area limited by BI = 28, then the portion of the fire prescription based on the National Fire-Danger Rating System is satisfied.

As the fire season progresses, current information on weather, fire danger, fire activity, and prescription criteria must be readily available, as illustrated in figure 12. The NFDRS chart is a visual aid that clearly illustrates the limits determined from the National Fire-Danger Rating System.

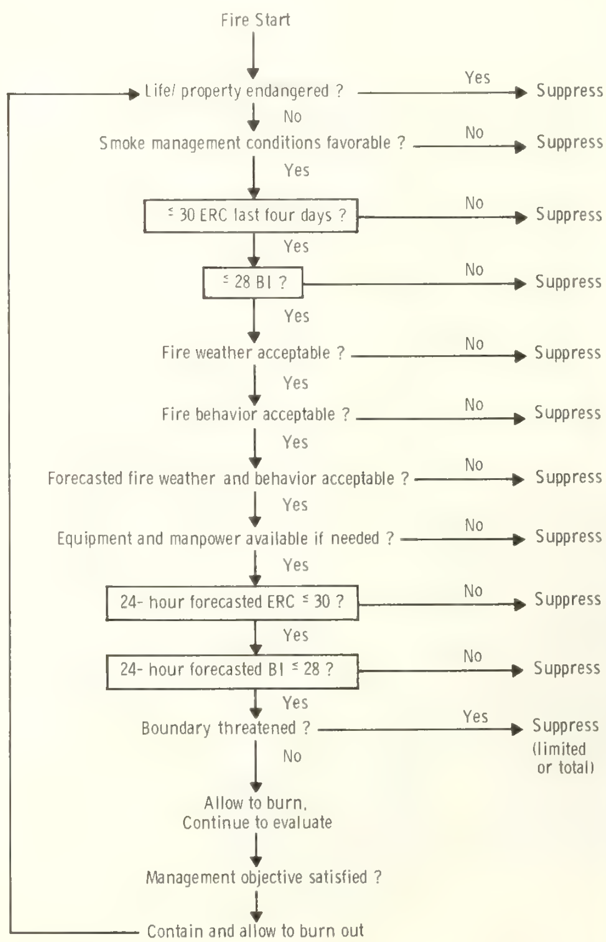

Figure 10.—Example flow chart for managing fires on big-game spring and winter ranges on operational fire management areas.

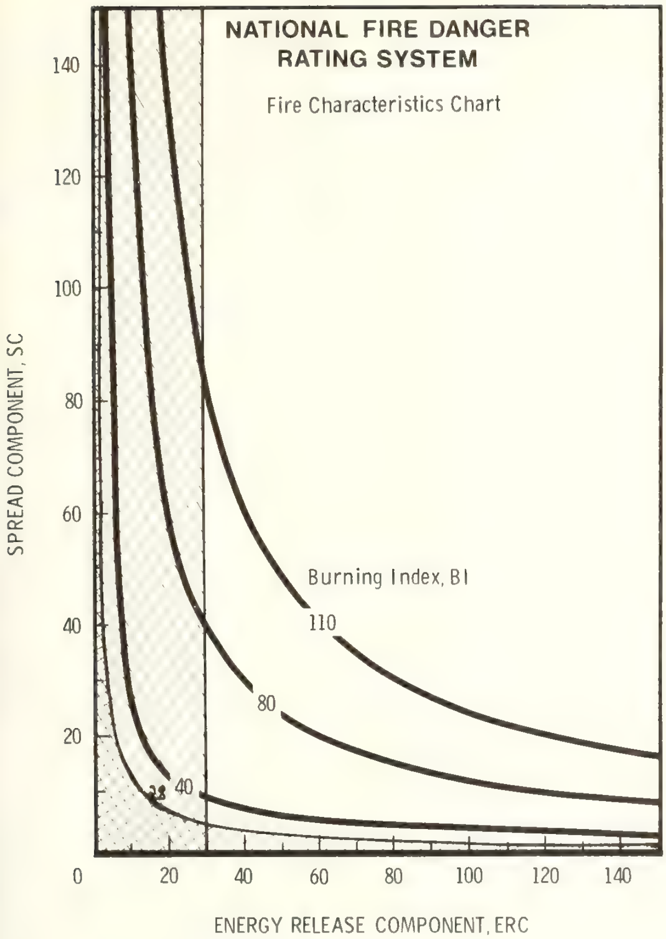

Figure 11.—NFDRS chart used to illustrate the limits on BI and ERC given in the flow chart in figure 10. For the portion of this fire prescription that is based on NFDRS indexes to be satisfied, plotted points from the last 4 days must fall to the left of the vertical line where ERC = 30 and the current day's point and the point forecasted for the next day must fall in the smaller area limited by the BI = 28 line.

Figure 12.—The fire characteristics chart can be part of a display that includes current information on weather, fire danger, fire activity, and prescription criteria that a fire manager uses to make decisions.

EXAMPLE: BRIEFINGS

During the fire season, briefings are often held to describe the general fire situation. The audience can include members of the news media, staff personnel, or others who are not familiar with the National Fire-Danger Rating System. Statements such as "the fire danger is high" or "the burning index is 85" can be misinterpreted. The NFDRS chart can serve as a visual aid and focal point for discussion. The chart can be explained easily: as a point falls farther to the right on the chart, there is an indication that fires will be hotter. A point falling farther up on the chart indicates the potential for faster spreading fires. Overall severity increases as a point falls farther from the origin in either direction.

Consider the following briefing of fire danger of a USDA Forest Service region, represented by the fire characteristics chart in figure 13.

> The fire danger of most of the west side of the region is low as indicated by point A, although there are a couple of districts that may cause problems (point B). Point C refers to the fire danger on the east side of the region. If we have another week of dry weather, the situation on the east side could become critical (point D).

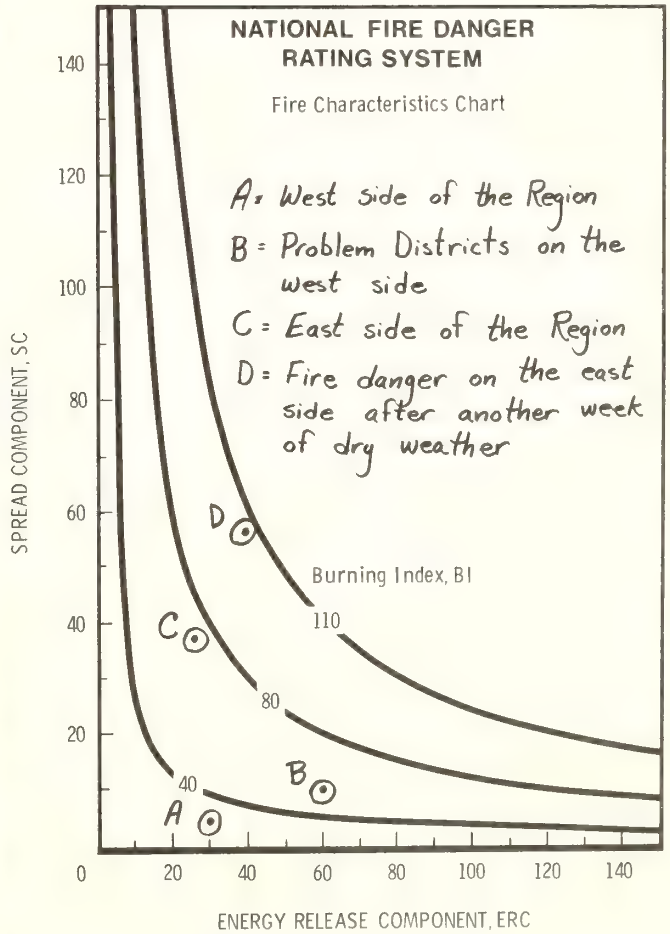

Figure 13.—NFDRS chart used in a briefing of current and potential fire danger.

FORMS OF THE CHART

The fire behavior chart and the NFDRS chart illustrated in figures 1 and 2 have scales that do not cover the entire range of possible values. The scales were chosen to give resolution to the lower values and allow the majority of values to be plotted on the chart. Nevertheless, some points will fall beyond the limits of the graph. A form of the fire behavior chart that overcomes this limitation uses logarithmic scales on the axes. In this way the entire range of values can be covered. The curved flame length lines become straight lines on the log scale version of the chart.

Figure 14 shows six points plotted on both linear and logarithmic scale fire behavior charts. This illustrates that a relatively small change in the behavior of a low-intensity fire is amplified, and a large change in the behavior of a high-intensity fire is compressed on the logarithmic chart. Because a primary purpose of the fire characteristics chart is to visually illustrate changes in fire behavior, care should be taken in interpretation of relative location of points plotted on the logarithmic chart.

It may be necessary to change the scales of a chart primarily used for a specific fuel type. For example, a chart primarily used to display fire behavior predictions in logging slash should have an expanded heat-per-unit area axis and a truncated rate-of-spread axis. Such a chart is shown in appendix B, along with other full-size charts suitable for reproduction. Appendix A offers the equations used in creating the fire characteristics charts.

An NFDRS chart can illustrate NFDR manning classes for a specific area. USDA Forest Service fire specialists generally determine manning classes from the 90th and 97th percentile burning index values for a specific station and fuel model. The percentile values are determined from historical fire weather observations and provide criteria for ranking the relative severity of the burning conditions on a given day. Appendix A includes an example showing how to design an NFDRS chart where BI lines designate manning class levels.

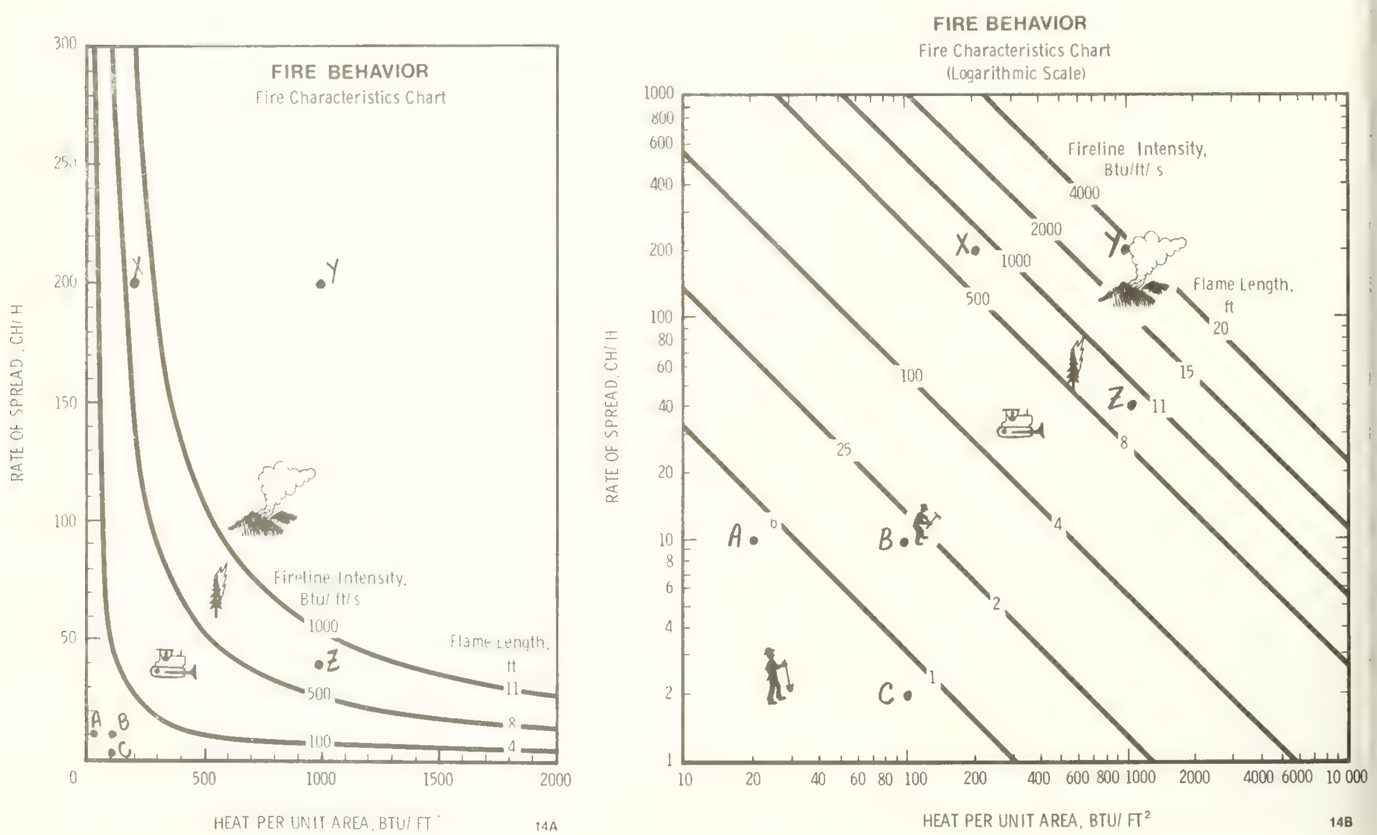

Figure 14.—The same six points (A, B, C, X, Y, Z) plotted for comparison on both a linear scale (A) and a logarithmic scale (B) fire behavior chart.

SUMMARY

Fire characteristics charts can be used to plot either site-specific fire behavior predictions or National Fire-Danger Rating System indexes. Because several aspects of fire behavior are plotted as a single point, the chart aids a user in assessing overall fire characteristics. The chart lends itself to a wide range of potential uses, the most significant being communication of quantitative values in a form that is easily understood.

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APPENDIX A
Equations for Compiling the Fire Characteristics Charts

The equation used to plot the curves on the NFDRS chart is

$$SC = \frac{0.091 \times BI^{2.17}}{ERC} \tag{1}$$

where
SC = spread component
ERC = energy release component
BI = burning index.

The equation used to plot the curves on the fire behavior chart

$$R = \frac{55\ I_B}{H_A} \tag{2}$$

where
R = rate of spread, chains/h
I_B = fireline intensity, Btu/ft/s
H_A = heat per unit area, Btu/ft^2.

The relationship between fireline intensity and flame length is given by the following equation:

$$F_L = 0.45\ I_B^{0.46} \tag{3}$$

where
F_L = flame length, ft
I_B = fireline intensity, Btu/ft/s.

Determination of Heat Per Unit Area

Heat per unit area is a direct output of the TI-59 fire behavior program. However, it cannot be read directly from the nomograms, nor is it an output value from most available computer programs. Although a point can be plotted on the fire behavior chart given rate of spread and fireline intensity or flame length, it is easier if a heat per unit area value is available.

To modify an existing computer program, use a reformulation of equation (2)

$$H_A = \frac{55\ I_B}{R}$$

where
H_A = heat per unit area, Btu/ft^2
I_B = fireline intensity, Btu/ft/s
R = rate of spread, chains/h.

The X axis of the upper right-hand graph of the nomograms as originally published by Albini (1976a) i reaction intensity (Btu/ft^2/min). The label was eliminated on subsequent revisions for fire behavior officer (FBO) training. The nomograms to be publish by Rothermel (in preparation) will have heat per unit area on that axis.

The relationship between reaction intensity and he per unit area is

$$H_A = I_R \frac{384}{\tilde{\sigma}}$$

where
H_A = heat per unit area, Btu/ft^2
I_R = reaction intensity, Btu/ft^2/min
$\tilde{\sigma}$ = characteristic surface-area-to-volume ratio c the fuel array, ft^2/ft^3
$\frac{384}{\tilde{\sigma}}$ = residence time, min (Anderson 1969).

The labels for heat per unit area can be added to th horizontal axis on the upper right-hand quadrant of the nomograms, using the scales given in figure 15. The scale is the same for both the low and high windspee options on all versions of the nomograms. Use of the nomograms does not change, as illustrated in the example in figure 16. Heat per unit area is read when the first constructed vertical line intersects the newly labeled axis.

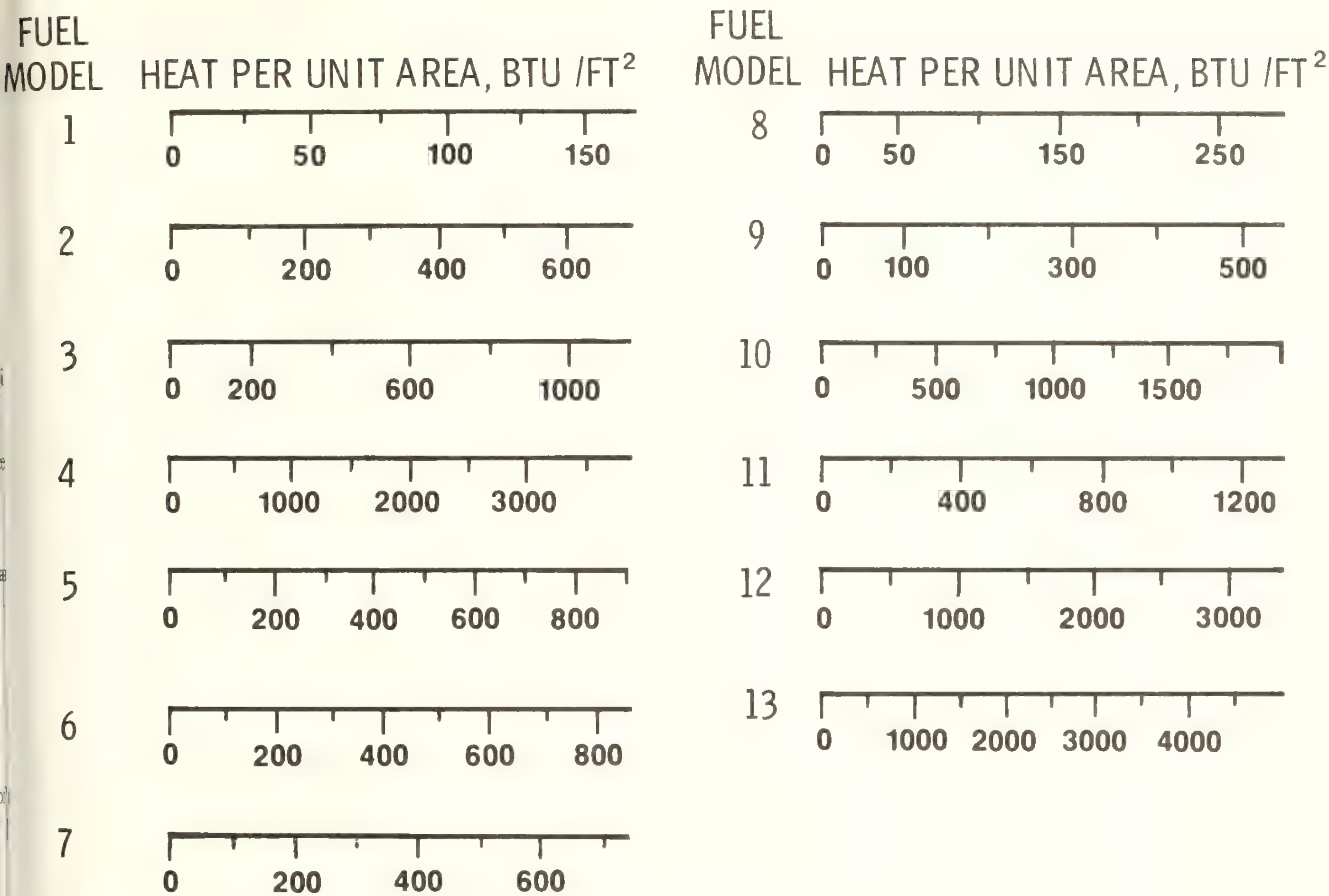


Figure 15.—Heat-per-unit-area scales can be transferred to the high or low windspeed options of the fire behavior nomograms (FBO or Albini 1976a). The scale for the appropriate fuel model is transferred to the horizontal axis of the upper right-hand graph.

Input:		Output:	
Fuel Model 8		Rate of spread	= 1.75 chains/h
Dead fuel moisture	= 8%	Flame length	= 1 ft.
Effective windspeed	= 5 mi/h	Fireline intensity	= 5 Btu/ft/s
		Heat per unit area	= 175 Btu/ft^2

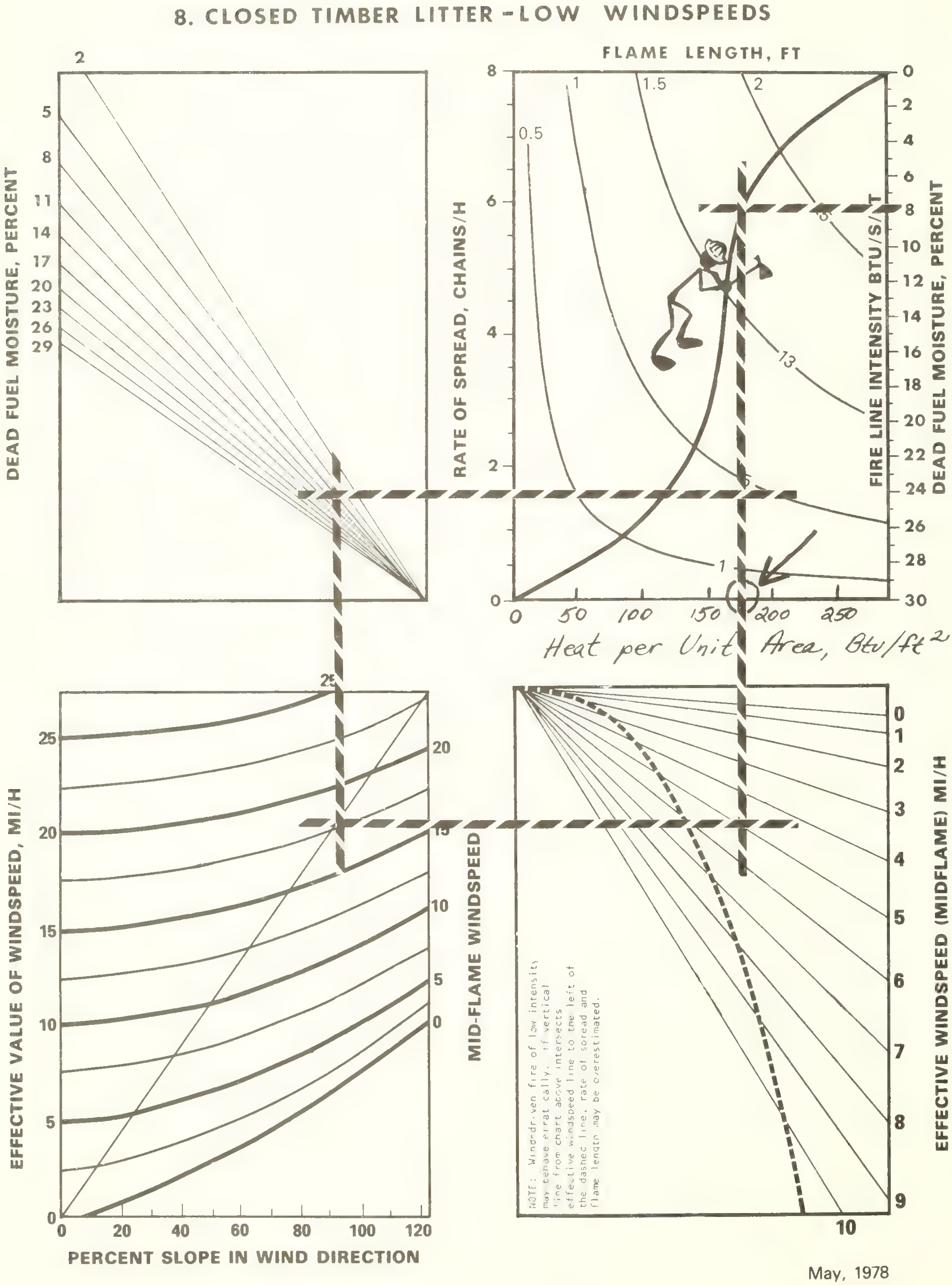


Figure 16.—Example of the use of a nomogram after the heat-per-unit-area label has been transferred from figure 15.

Creation of a Custom NDFRS Chart

An example of a custom NFDRS chart is shown in figure 17. This chart is for the Ninemile District (Lolo National Forest), fuel model G. Manning classes are based on burning index.

The steps to creation of such a chart are as follows:

1. Run the FIRDAT program as described in the User's Guide to FIREFAMILY (Main and others in press) to determine the 90th and 97th percentile values of BI and the maximum SC and ERC values.

   For this example, based on the 1970-79 weather data, the 90th percentile of BI is 56.38 and the 97th percentile is 69.74. The maximum SC for this period was 49 and the maximum ERC was 60.
2. Calculate the manning class boundary values as described in the User's Guide to AFFIRMS (Helfman and others 1980).

   For six manning classes in this example, the results are:

Displayed manning class	Upper value for class (burning index)	
1	[1](MI90)/4	= 14
2	(MI90)/2	= 28
3 –	(MI90)(3/4)	= 42
3 +	(MI90)	= 56
4	MI97	= 70
5	More than MI97	

3. Draw the axes for the chart based on the maximum values for SC and ERC.

   In this case, the axes are extended beyond the 10-year maximums to SC = 60 and ERC = 70.
4. Locate the curves for each of the BI values determined in step 2 above using equation (1). Find SC for several values of ERC. The upper end-points of the BI curves can most easily be located by using an alternate form of equation (1):

$$ERC = \frac{0.091 \times BI^{2.17}}{SC}$$

To locate the BI = 56 curve in figure 17, find ERC when SC = 60 (the maximum SC for this chart):

$$ERC = \frac{0.091 \times 56^{2.17}}{60} = 9.4$$

Find the other endpoint of the curve by calculating SC when ERC = 70 (the maximum ERC for this chart):

$$SC = \frac{0.091 \times 56^{2.17}}{70} = 8$$

Similarly when ERC = 40 and 20, the calculated values for SC are 14 and 28, respectively. A smooth curve is drawn through the following four points:

ERC	SC
9	60
20	28
40	14
70	8

The curves for the other manning class divisions (BI = 14, 28, 42, and 70) are located in a similar manner.

[1]This notation corresponds to that used in the AFFIRMS manual. MI90 = 90th percentile manning index and MI97 = 97th percentile manning index.

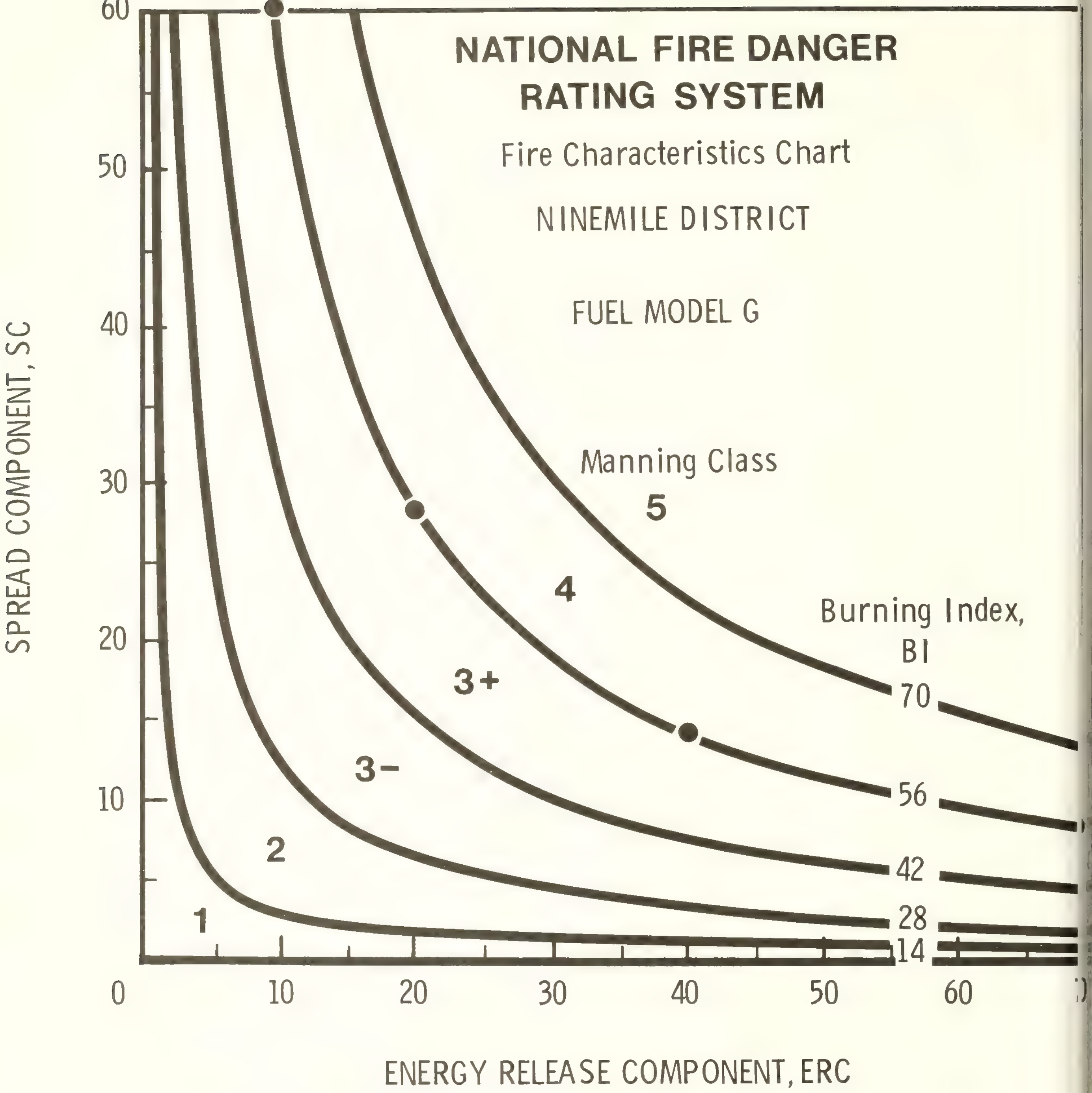
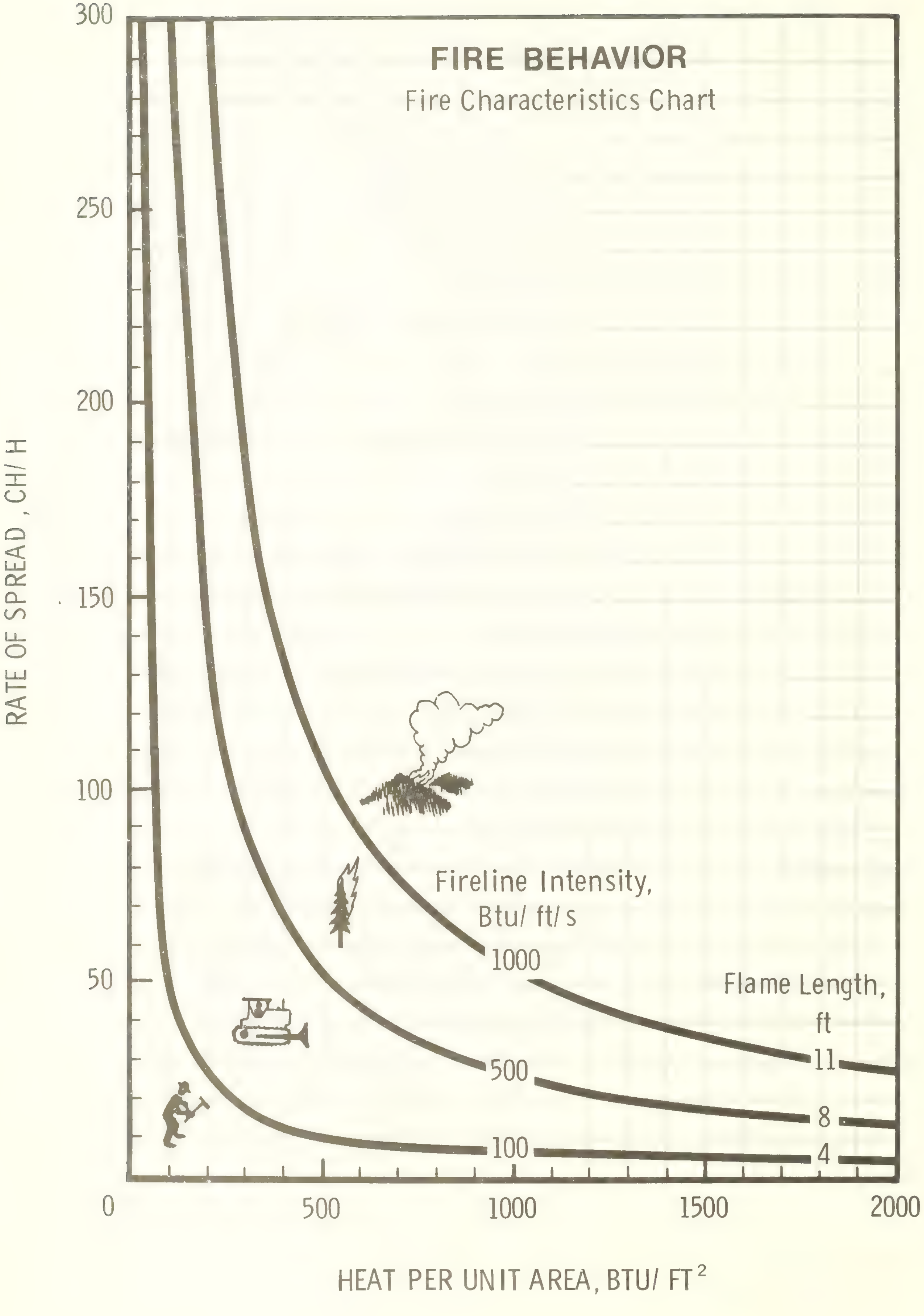
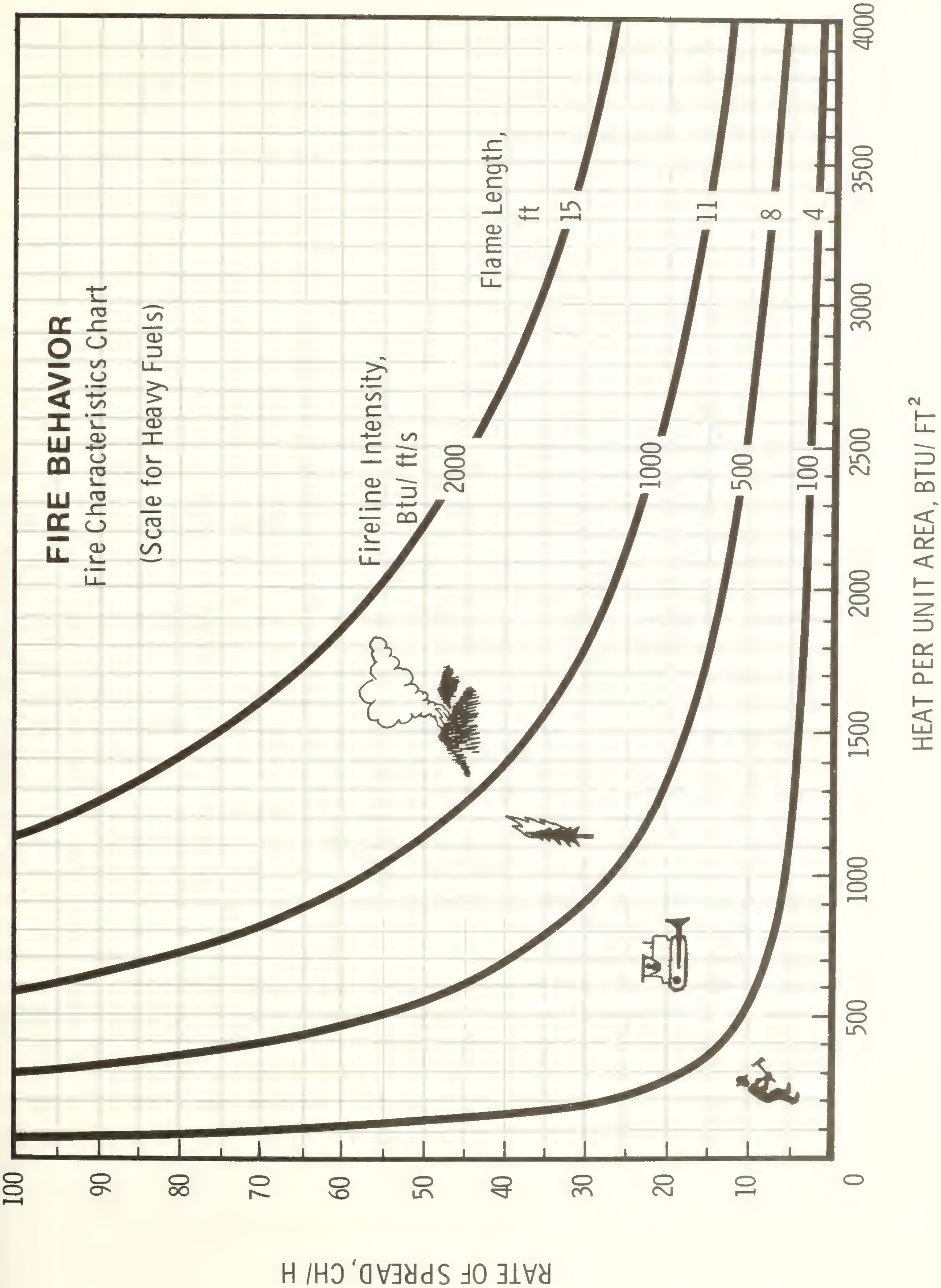


Figure 17.—Example of a custom NFDRS chart, where the BI lines correspond to manning class cutoff values. Manning classes are based on 1970-79 weather for Ninemile Ranger Station (241507).

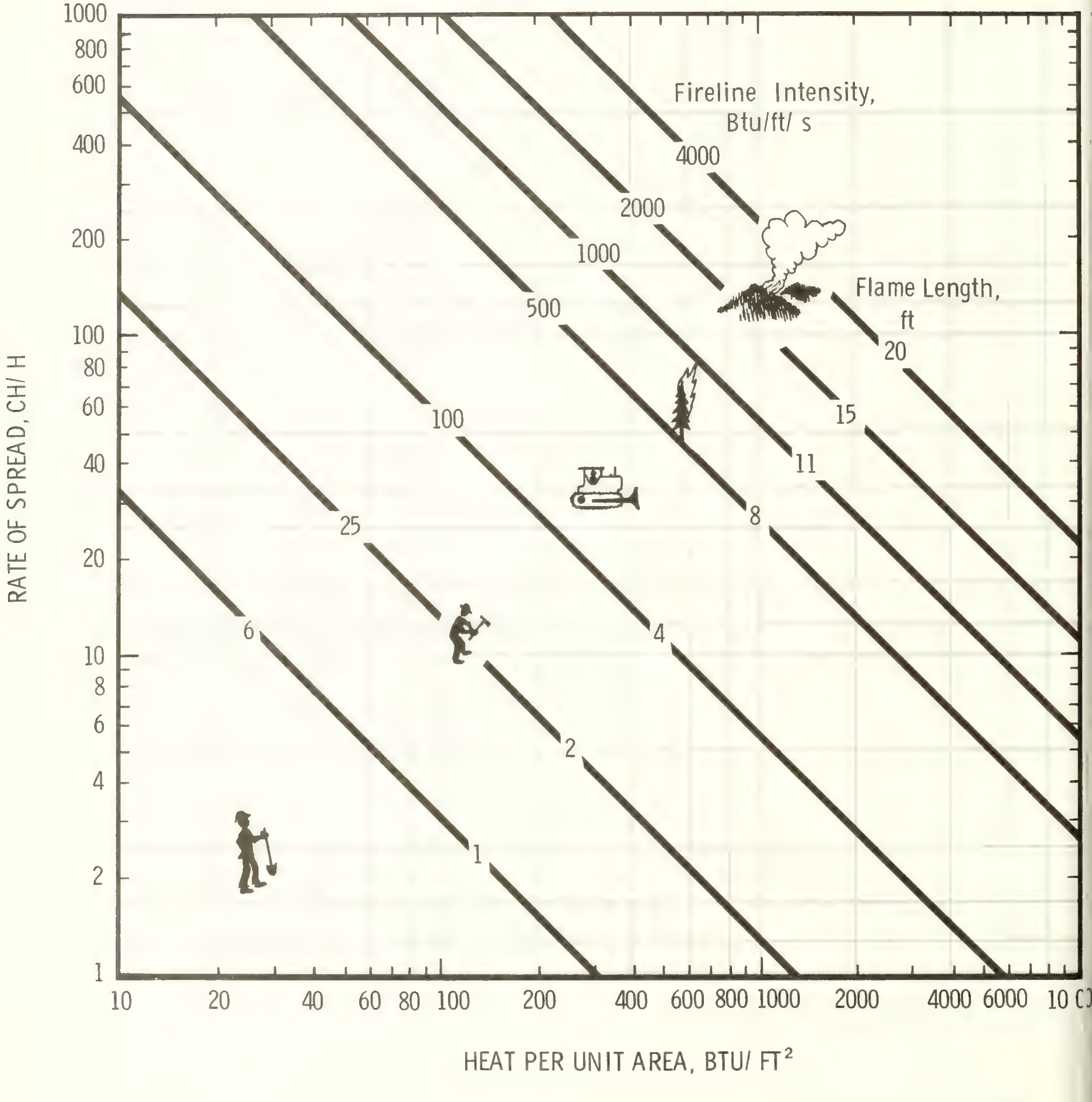
APPENDIX B
Fire Characteristics Charts
Suitable for Copying

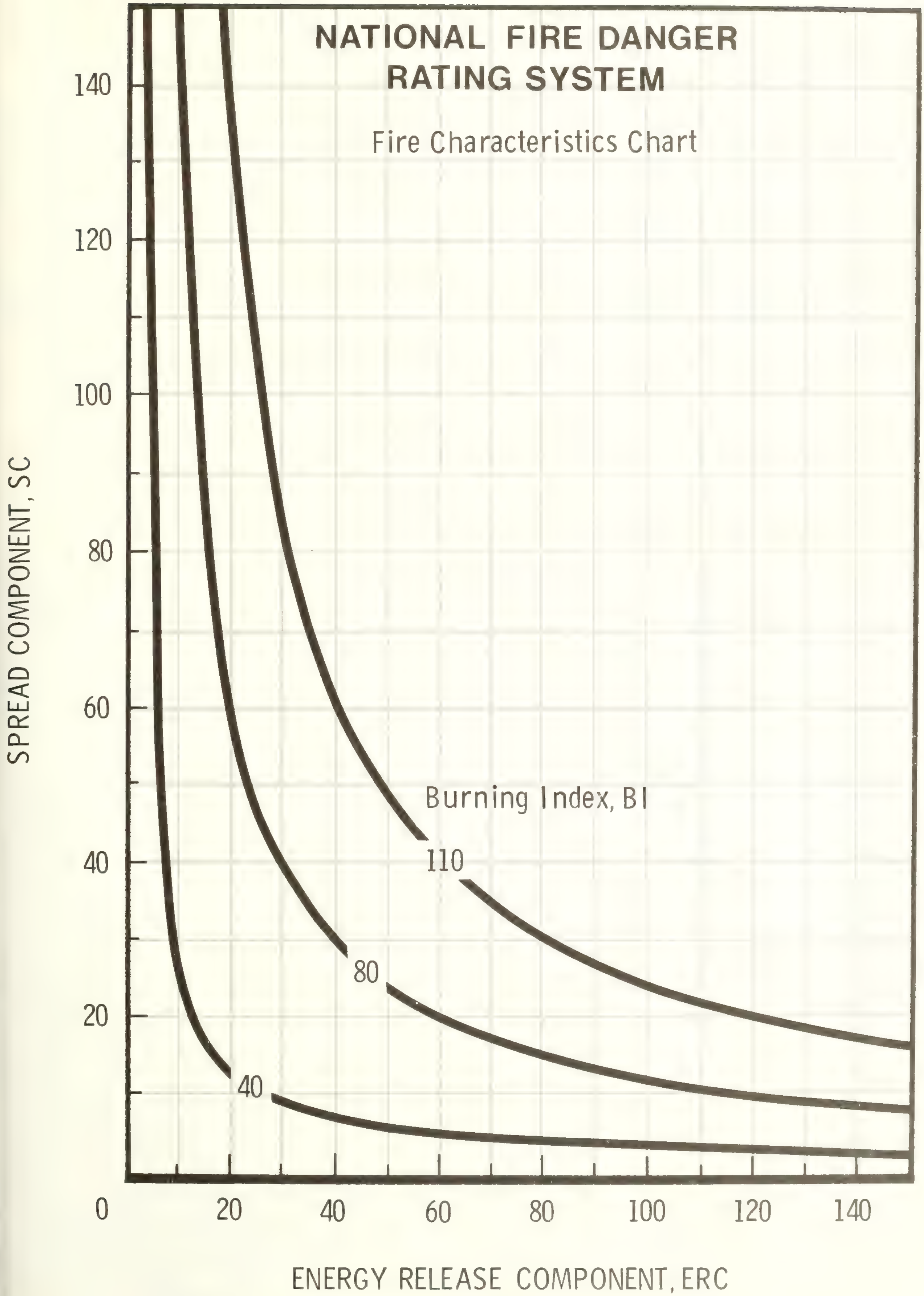

FIRE BEHAVIOR
Fire Characteristics Chart
RATE OF SPREAD, CH/H
300
250
200
150
100
50
0
500
1000
1500
2000
HEAT PER UNIT AREA, BTU/ FT²
Fireline Intensity, Btu/ ft/ s
1000
500
100
Flame Length, ft
11
8
4


FIRE BEHAVIOR
Fire Characteristics Chart
(Scale for Heavy Fuels)
Fireline Intensity,
Btu/ ft/s
2000
1000
500
100
Flame Length,
ft
15
11
8
4
RATE OF SPREAD, CH/ H
100
90
80
70
60
50
40
30
20
10
0
500
1000
1500
2000
2500
3000
3500
4000
HEAT PER UNIT AREA, BTU/ FT²

FIRE BEHAVIOR

Fire Characteristics Chart
(Logarithmic Scale)





☆ U.S. GOVERNMENT PRINTING OFFICE: 1982—576-026/19 REGION No. 8

Andrews, Patricia L.; Rothermel, Richard C. Charts for interpreting wildland fire behavior characteristics. Gen. Tech. Rep. INT-131. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1981. 21 p.

The fire characteristics chart is proposed as a graphical method of presenting two primary characteristics of fire behavior—spread rate and intensity. Its primary use is communicating and interpreting either site-specific predictions of fire behavior or National Fire-Danger Rating System (NFDRS) indexes and components. Rate of spread, heat per unit area, flame length, and fireline intensity, are plotted on a fire behavior chart. Spread component, energy release component, and burning index are plotted on an NFDRS chart. Specific examples illustrate potential application.

KEYWORDS: fire behavior, fire spread, fire intensity, fire-danger rating, National Fire-Danger Rating System

The Intermountain Station, headquarted in Ogden, Utah, is one of eight regional experiment stations charged with providing scientific knowledge to help resource managers meet human needs and protect forest and range ecosystems.

The Intermountain Station includes the States of Montana, Idaho, Utah, Nevada, and western Wyoming. About 231 million acres, or 85 percent, of the land area in the Station territory are classified as forest and rangeland. These lands include grasslands, deserts, shrublands, alpine areas, and well-stocked forests. They supply fiber for forest industries; minerals for energy and industrial development; and water for domestic and industrial consumption. They also provide recreation opportunities for millions of visitors each year.

Field programs and research work units of the Station are maintained in:

Boise, Idaho

Bozeman, Montana (in cooperation with Montana State University)

Logan, Utah (in cooperation with Utah State University)

Missoula, Montana (in cooperation with the University of Montana)

Moscow, Idaho (in cooperation with the University of Idaho)

Provo, Utah (in cooperation with Brigham Young University)

Reno, Nevada (in cooperation with the University of Nevada)

United States
Department of
Agriculture

Forest Service

**Intermountain
Forest and Range
Experiment Station
Ogden, UT 84401**

General Technical
Report INT-132

July 1982

Management Consequences of Alternative Harvesting and Residue Treatment Practices— Lodgepole Pine

Robert E. Benson

Approved for publication by Intermountain Station
March 1982

PREFACE

This study was undertaken as a cooperative effort among Intermountain Station, Region 4, and Champion International on the Bridger-Teton National Forest in 1971. At the time, land managers were primarily concerned about management of logging residues, particularly in reducing visual impacts and costs of treatment.

The main goal of the study was to evaluate equipment and methods for chipping residues on site. Research efforts in monitoring the longer term consequences of the study were of necessity designed to fit the harvest activities. The harvesting operations, costs, and initial responses on the site have been previously published in various reports.

In the decade since study was begun, there have been marked changes in wood utilization. Land management and planning requirements have greatly expanded the need for information regarding long-term impacts of alternative harvesting practices. Limitations in the initial scope and design of the study were such that some important questions cannot be answered, except as speculations. Nevertheless, our intent is both to present research data and to integrate findings into a useful reference for managers.

This report stems from the need to interrelate individual findings in a manner that illustrates the consequences of management decisions. The manager may not have the time or the skills needed to correlate many separate results.

The goal is to translate the physical and biological responses of the harvest activities into interpretations readily adapted to the manager's needs. Where data from this study are lacking or inconclusive, perhaps the methodology and references will provide some assistance. It should be pointed out, however, that while the intent is to integrate and reference research findings, this report is not a "cookbook" or substitute for the manager's on-the-ground knowledge and judgment.

This report summarizes and integrates the findings of a team of Intermountain Station scientists and cooperators. The principal Forest Service participants in the study are listed below, and sections prepared by individuals are identified in the text. Other sections were prepared by the study coordinator.

Robert E. Benson, Forestry Sciences Laboratory, Missoula (Study Coordinator)
Joseph V. Basile, Forestry Sciences Laboratory, Bozeman
James K. Brown, Northern Forest Fire Laboratory, Missoula
Dennis M. Cole, Forestry Sciences Laboratory, Bozeman
Norbert V. DeByle, Forestry Sciences Laboratory, Logan
Rulon B. Gardner, Forestry Sciences Laboratory, Bozeman (retired)
George E. Gruell, Northern Forest Fire Laboratory, Missoula
Alan E. Harvey, Forestry Sciences Laboratory, Moscow
Roger D. Hungerford, Forestry Sciences Laboratory, Missoula
James E. Lotan, Northern Forest Fire Laboratory, Missoula
Paul E. Packer, Forestry Sciences Laboratory, Logan (retired)
Wyman C. Schmidt, Forestry Sciences Laboratory, Bozeman
Bryan D. Williams, Forestry Sciences Laboratory, Logan

In addition to the study team members who authored individual sections, several team members and cooperators made substantial contributions of fieldwork, data, or analyses, as described below:

George E. Hart, Robert W. Hennes, John J. Skujins, and **Alvin R. Southard.**—These cooperators at Utah State University, Logan, contributed fieldwork, analyses, and reports that are incorporated into the sections on soil properties and nutrients, and soil microorganisms.

George E. Gruell, Northern Forest Fire Laboratory, while stationed on the Bridger-Teton, conducted field assessments and made summaries that are incorporated in sections on wildlife responses, wildlife values, and grazing values.

Reed Stalder, while stationed in the Regional Office, Ogden, made field assessments and summaries that are incorporated into the section on esthetic and recreational values.

Paul E. Packer and Bryan D. Williams conducted fieldwork and contributed reports that are incorporated into the soil and water section.

Resources Evaluation Research Work Unit, Intermountain Station, Ogden, provided pre- and postharvest inventory data on timber, residues, and ground cover.

The Supervisor's Office and the Gros Ventre District of the Bridger-Teton provided continuing assistance in locating the field site, arranging work schedules, and supporting the research team in conducting research and field workshops.

A special acknowledgment goes to Dr. DeByle who provided valuable comments throughout all phases of preparing this report.

RESEARCH SUMMARY

A harvesting study in mature lodgepole pine compared four harvesting and logging residue treatments. Residues were piled and burned, broadcast burned, chipped and spread back on the ground, or removed from the site. On all four harvesting treatments regeneration by planted seedlings, direct seeding, and natural regeneration was compared.

The harvesting was done in 1971, and since that time a series of research studies has measured the effects of the treatment on soils, soil microbiology, nutrients, water, microclimate, tree survival and growth, vegetative development, wildlife habitat, and esthetics. A comparison of logging costs and returns, and projected future stand conditions are included in an economic analysis.

The initial net dollar returns were slightly higher with the residue-burned treatments than when residues were removed or chipped. Utilization standards and wood values have changed considerably in the past decade.

The effects of the different treatments on the site varied. In general, survival and growth of regeneration was best on the residue-burned treatments. The chip-spread treatment greatly inhibited regrowth of both trees and other vegetation. There was no clear picture of why these differences occurred, but on the residue-removed and chip-spread treatments presence of phenols in the water, creation of unfavorable microsite conditions, and soil compaction may have contributed. Based on initial mortality and growth, future stands will probably have notable differences in stocking volume.

The initial visual impact of the residue-removed treatment was less severe than the residue-burned treatments. But the burned treatments provided better habitat for most wildlife species.

It is evident that different harvest treatments result in a complex interaction among the different impacts. An estimate of how different use opportunities are affected, and a method for comparing tradeoffs are presented.

THE AUTHOR

ROBERT E. BENSON is a research forester assigned to the Systems of Timber Utilization for Environmental Management Program, and has been with the Intermountain Station in Ogden and Missoula. His research includes studies in forest economics, wood products marketing, forest inventories, and resource analyses.

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United States
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Forest Service

**Intermountain
Forest and Range
Experiment Station
Ogden, UT 84401**

General Technical
Report INT-132

July 1982

Management Consequences of Alternative Harvesting and Residue Treatment Practices— Lodgepole Pine

INTRODUCTION

In recent years there has been growing concern over timber ıarvesting practices and the disposal of the resulting logging ·esidues. Although various methods of harvesting and han- dling residues have been considered, economic feasibility of he alternatives and their effects on the forest resource and 'uture management have remained in question.

In 1971 the Intermountain Forest and Range Experiment Station, the Intermountain Region, and Champion nternational Inc. undertook a cooperative study to evaluate everal systems of harvesting mature lodgepole pine (*Pinus ontorta* Dougl.) and to compare postharvest treatments. Studies included effects of different treatments on soil and vater, tree regeneration and vegetation, esthetics, harvesting osts, and management activities. Principal design and analysis of the study was by the Intermountain Forest and Range Experiment Station, with the Teton National Forest, the ntermountain Region, and the Forest Products Laboratory ooperating. (In 1973 the Teton National Forest was combined nto the Bridger-Teton National Forest.)

Since 1971, utilization has changed significantly. Rising emand for wood products and a declining timber base have ncreased the feasibility of using more of the dead material. A ubstantial market for house logs using dead trees has devel- ped throughout the lodgepole region, and use is increasing or stovewood, pulp chips, and other products. Many of the roblems of processing dead timber for lumber have been vercome.

The Study Site

The study site is located near the Union Pass area southwest of Dubois, Wyo., on the Bridger-Teton National Forest (fig. 1). This area is a high, gently rolling plateau about 9,000 to 9,800 ft (2 700 to 3 000 m) elevation. Slopes range from 5 to 25 percent.

The area consists of a mixture of very large open sagebrush and lupine meadows, wet meadows, and extensive timber stands interspersed with small meadows and potholes. There are sizable populations of moose, antelope, elk, and some deer. Cattle are grazed throughout the area in the summer, and there is considerable fishing, hunting, and other recreation in the area.

Soils on the study site developed in glacial till, and classify as Mollic Cryobaralfs and Mollic Cryochrepts.[1] The surface organic horizon is 0.8 to 1.2 in (2 to 3 cm) thick. The underlying mineral soil is typically loam, progressing downward to sandy and gravelly loam.

Lodgepole pine (*Pinus contorta* Dougl.) comprises 75 to 90 percent of the timber volume. Virtually none of the lodge- pole pine is serotinous. Engelmann spruce (*Picea engelmannii* Parry), subalpine fir (*Abies lasiocarpa* [Hook] Nutt.), and limber pine (*Pinus flexilis* James) make up the remainder. The principal habitat type is *Abies lasiocarpa/Vaccinium scoparium* (Steele and others 1979).

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[1]Reported by DeByle (1980), based on his personal communication with A. R. Southard, Utah State University, Logan.

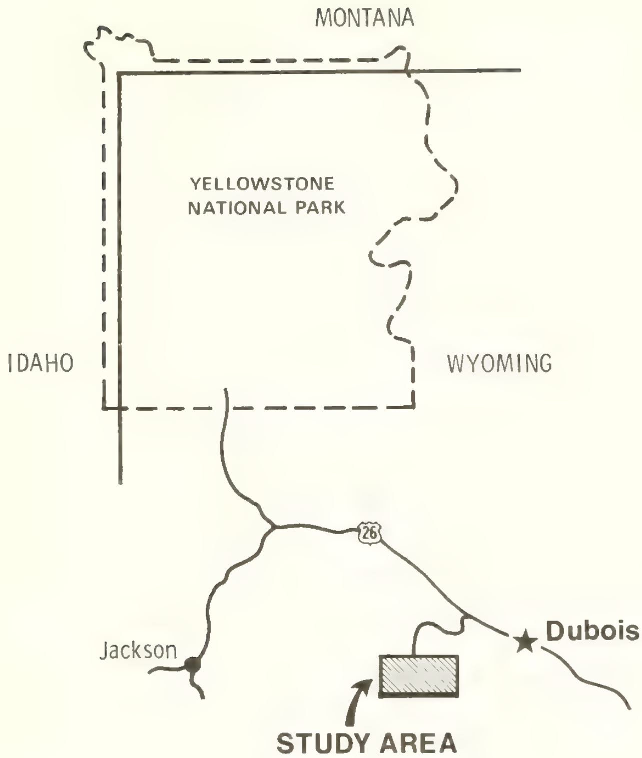


Figure 1.—Location of study area, Bridger-Teton National Forest.

The study site is typical of high-elevation, mature lodgepole pine stands: about 300 live trees per acre (740/ha) and 100 dead trees (250/ha), pole size (5 in [12.7 cm] d.b.h.) or larger. The principal stand is even-aged, about 160 years old. Most of the understory conifers are limber pine seedlings.

The total volume of standing trees ranges from about 7,000 to 9,600 ft^3/acre (2 800 to 3 900 m^3/ha). About 75 percent of this is sound sawtimber trees that is net volume after deducting for defect; 10 percent is the top portions of sound trees; and the remaining 15 percent is small trees, cull trees, and cull portions of saw logs. Detailed timber data on the study units are presented in the appendix.

Near the study site, logging was begun in the 1950's and has continued to the present. Because stands are old and have no manageable understory, the usual harvest method is to clearcut in units of 15 to 30 acres (6 to 12 ha), although some of the first cutting units were larger. Residues were tractor-piled and burned, and sites were usually regenerated by planting. Figure 2 shows a typical cover pattern for the area: meadows 25 percent, uncut forest 60 percent, and cutover 15 percent.

Understory vegetation is relatively sparse on the site due to a short growing season, limited moisture during the growing season, and a dense, uniform tree crown overstory. The understory averages about 250 to 300 lb/acre (280 to 335 kg/ha), with the major components as follows:

Component	Percent
Shrubs	34
Seedlings	10
Forbs	39
Moss	12
Grass	5
	100

The study area did not show evidence of sizable fires during the life of the stand, but fire is apparently a common part of the forest cycle. The fire-free interval is no doubt relatively long, perhaps several hundred years.

Study Design and Treatments

The study site consisted of four 20-acre (8-ha) units harvested by clearcutting. Two units were logged with conventional practices for the area at that time; green saw logs to a 6-in (15-cm) top were removed, and the remaining material was left for burning on the site (''green'' includes recently dead trees that are sound). The other two units had residues removed. In addition to taking out the merchantable saw logs, virtually all other material was yarded and chipped. On these units a feller-buncher and rubber-tired grapple skidder were used in combination with a mobile chipper (fig. 3). The equipment and the utilization methods were new to the area. The logging and postharvest treatments are as follows (refer to fig. 4).

Units 1 and 4—Residues Removed

—Logging (summer 1971): feller-buncher and grapple skidder.

—Utilization: all pieces down to a 3-in diameter by 8 ft long (7.6 cm by 2.4 m) were skidded to landing, where green saw logs were bucked out.

—Residue treatment: all residues were chipped and piled on the site.

—Half of each unit was left as is after the removal of residues. On the other half of each unit, chips were spread back on the ground during the fall of 1972 and spring 1973 in approximately the same amount as residues were removed (''chip-spread''). This resulted in a bed of chips about 4 to 6 in (10 to 15 cm) deep.

Units 2 and 3—Conventional Utilization

—Logging: trees felled by chain saws, saw logs bucked out, and logs skidded to landing using rubber-tired tractors with chokers.

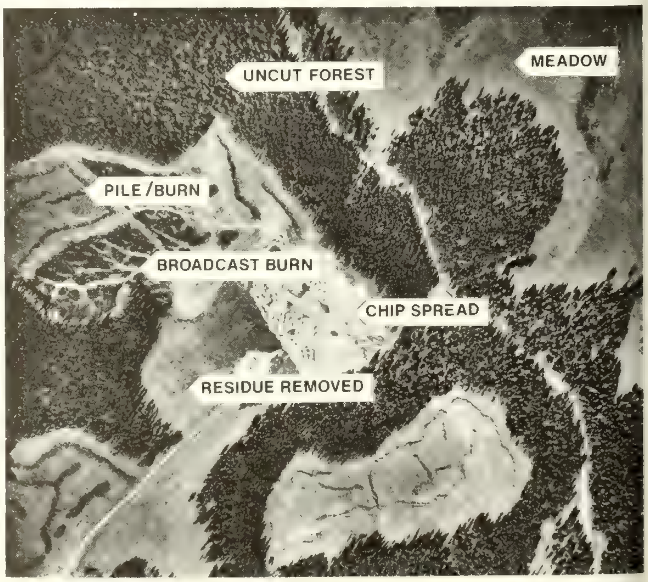


Figure 2.—Typical cover pattern for the study site.

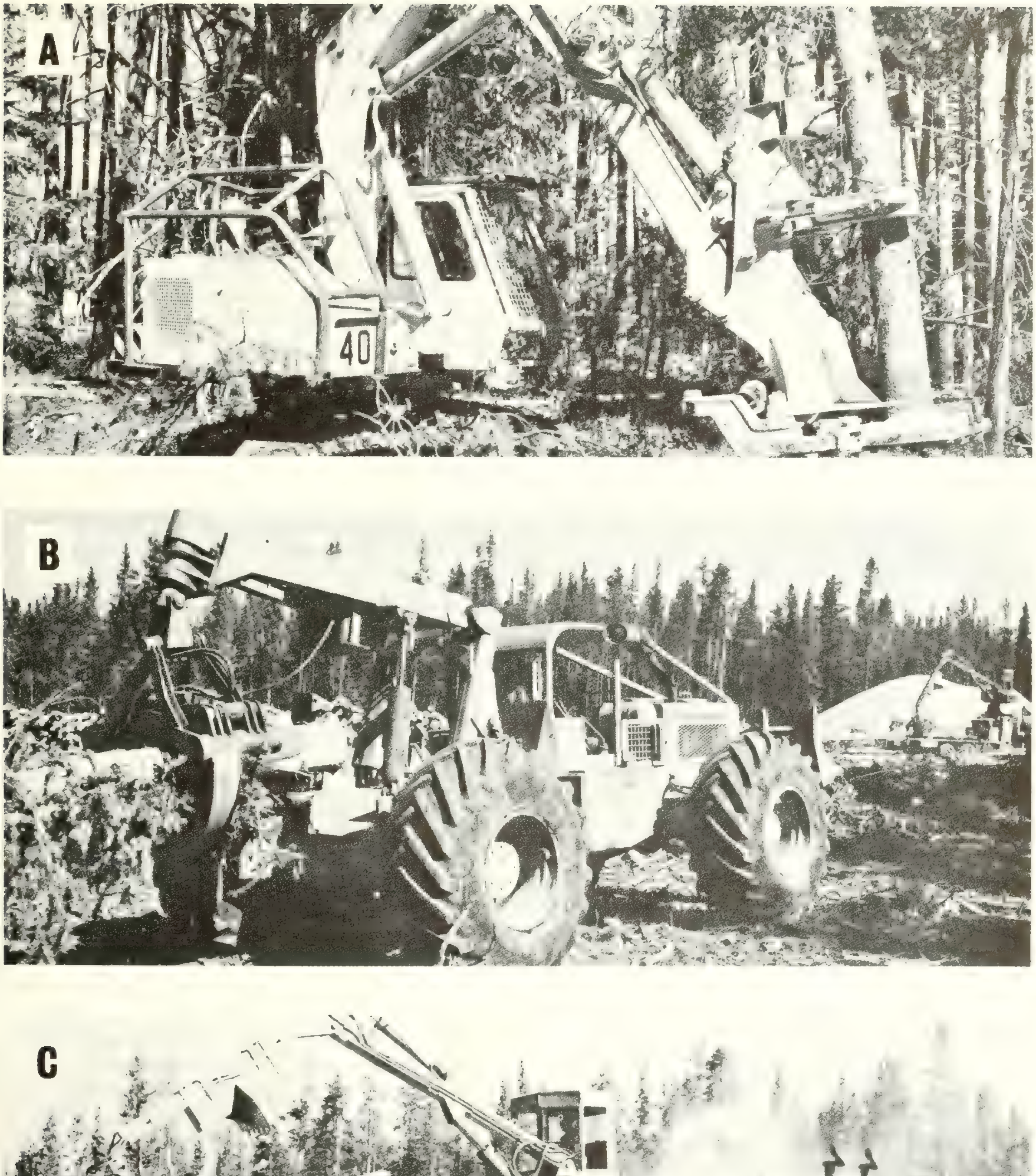


Figure 3.—Equipment used in residues-removed logging: (A) feller-buncher; (B) grapple skidder; (C) chipper.

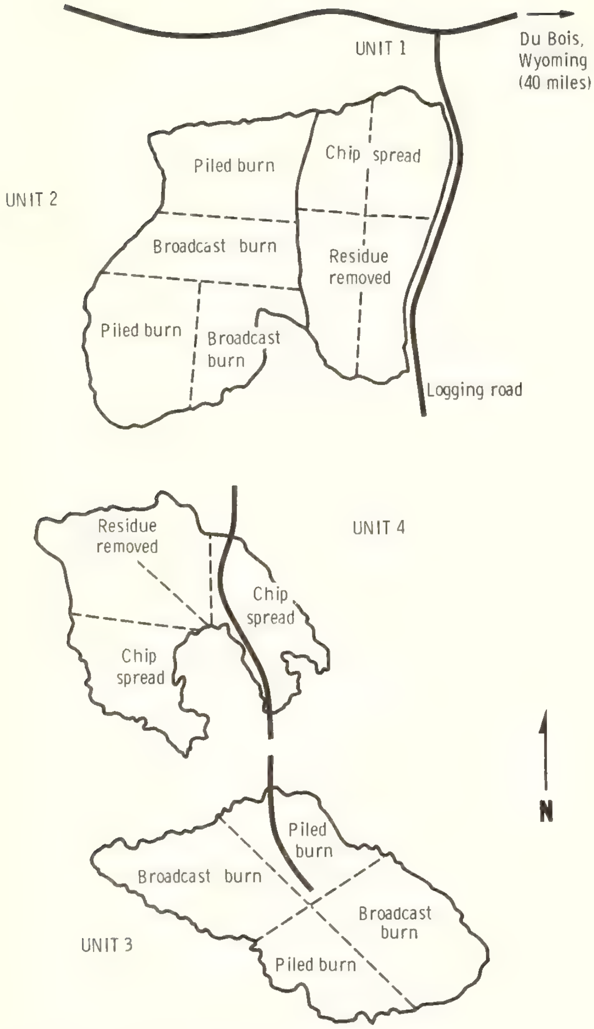


Figure 4.—Cutting units and residue treatments.

—Utilization: "conventional" utilization for the area—green saw logs to 6-in (15-cm) top diameter.

—Residue treatment: slash on half of each unit was left in place and broadcast burned in spring 1973. On the other half, slash was piled by crawler tractor with blade, and the piles burned in the fall of 1972.

Although there was no market for chips in the area in 1971, residues were chipped to estimate the costs of recovering fiber and to evaluate the impacts of removing residue from the site. Some chips were used for experimental products and some were used as ground cover at a local rodeo arena and campground. The chip-spreading was done to evaluate such a treatment as an alternative to burning slash.

To study tree regeneration, the quadrants on all units were divided into thirds. In June 1973 one-third of each quadrant was planted with 2-0 lodgepole pine, one-third was spot seeded to lodgepole pine, and the remaining third was left for natural regeneration. Planting and spot seeding were done in small, hand-scalped areas, each about 18 in (45 cm) square.

HARVEST AND POSTHARVEST ACTIVITIES

This section describes harvest methods, postharvest site treatment, and regeneration activities carried out during 1971-73 on the site. Most of these have been discussed in detail in earlier published reports. These reports are briefly summarized in this section and updated, where appropriate, with new information developed since the study was initiated.

Logging and Utilization

Logging in the conventional units described above was typical for the area at the time of study (1971). Green saw logs were the principal product, and a very limited amount of dead or small material was removed as saw logs. Saw logs were trucked to the Dubois, Wyo., sawmill.

Production time for logging equipment was recorded daily and volumes of saw log and chipped residues were measured. These data were combined with average equipment costs to derive logging productivity and costs. The 1971 costs of logging averaged from $31 to $35 per M bd.ft. for saw logs, and $19 to $20 per bone dry unit (BDU) of chips. These costs include all equipment, labor, and supervisory costs at the field level, and also hauling costs to Dubois, 40 miles. Details of the logging study were reported by Gardner and Hartsog (1973).

To make these data more generally applicable, hauling costs were deducted, and data were adjusted for differences in stand volumes on the different units, as described in the appendix. The 1971 and updated 1980 costs were as follows:

	1971	1980
Saw logs, stump to truck		
Conventional units, $/M bd.ft.	20.26	36.27
Residue-removed units, $/M bd.ft.	20.64	36.95
Chips, stump to truck, $/BDU ($/ft³)	13.09 (0.137)	23.43 (0.245)

On conventional logging units slash disposal was as follows: (1) piled with a crawler tractor, then burned (conventional method in the area); (2) left for broadcast burning, with no treatment except a bulldozed fireline. The costs of these treatments were:

	1971 dollars	1980 dollars
Pile/burn, piling, $/acre	35.71	63.92
Broadcast burn, fireline, $/acre	4.86	8.70

Fuels and Burning

James K. Brown and James E. Lotan

To assess the effects of the two utilization standards on fuel characteristics, fuels were inventoried before and after logging. Sampling was done using a grid. At each sample point, fuel loading (weight per unit area) by size class, fuel depth, duff depth, and percentage of ground cover were measured. The branch wood size classes were 0 to 0.20 in (0 to 0.5 cm), 0.21 to 0.60 in (0.5 to 1.5 cm), 0.61 to 3.0 in (1.5 to 7.6 cm), and larger than 3.0 in (7.6 cm). The first three classes correspond

Table 1.—Ground fuels before and after logging, by component weight and percent cover

Fuel item	Residue-removed			Conventional		
	Before	After	Change	Before	After	Change
	Tons/acre (metric tons/ha)					
Loading						
Needles	0	0.40	0.40	0	1.05	1.05
Branch wood, inch (cm)						
0.0-0.2 (0.0-0.5)	0.14	.10	–.04	0.20	.15	–.05
0.2-0.6 (0.5-1.5)	.82	1.32	.50	.96	1.92	.96
0.6-3.0 (1.5-7.6)	3.38	8.64	5.26	4.22	9.70	5.48
Total	4.34	10.46	6.12	5.38	12.82	7.44
	(9.7)	(23.4)	(13.7)	(12.1)	28.7)	(16.7)
Over 3.0 (7.6)	27.0	9.0	–18.0	16.5	44.0	27.5
	(60.5)	(20.2)	(–40.3)	(37.0)	(98.6)	(61.6)
	Percent					
Ground cover						
Mineral soil	2	42	+40	1	29	+28
Forest floor litter	48	26	–22	51	40	–9
Wood	21	31	+10	19	29	+10
Grass	22	0	–22	13	1	–12
Brush	2	0	–2	16	1	–17
	Inches (cm)					
Fuel depth	10.8	3.0	–7.8	13.7	7.4	–6.2
	(27.4)	(7.6)	(–19.8)	(34.8)	(18.8)	(–15.7)
Duff depth	.92	[1]		.92	[1]	
	(2.3)			(2.3)		

[1]Not measured.

to the 1-, 10-, and 100-hour moisture timelag classes used in the National Fire-Danger Rating System. Bulk density of the duff was determined from 10 samples of 1 ft^2 (929 cm^2) systematically taken in each stand.

Fuel loading for downed dead branch wood was determined using the planar intersect technique (Brown 1974). For material less than 3 in (7.6 cm) in diameter, a 5-ft (1.5-m) line transect was located at each grid point. The numbers of branch wood particles intersecting the vertical plane projected by the 5-ft (1.5-m) line were tallied for the first three size classes.

The weight of fuels and percentage of ground covered by fuels before and after harvesting are summarized in table 1. These measurements were taken prior to slash piling. After piling, the windrows covered approximately 18 percent of the surface of the pile/burn units, as measured on aerial photographs.

The main differences in the two harvesting treatments were in the amount of material larger than 3 in (7.6 cm) and total fuel depth after logging. On the residue-removed units, weight of material larger than 3 in (7.6 cm) was reduced to one-third of the prelogging amount. On the conventional units, fuel weight tripled. Although fuels larger than 3 in (7.6 cm) contribute little to the spreading flame front, they do contribute measurably to total fire intensity. Larger fuels also contributed to fire spread by compressing smaller sized fuels and thus increasing their flammability.

Fuel depth was reduced by both harvesting methods, primarily by removing grouse whortleberry (*Vaccinium scoparium*). Change in fuel depth, however, is not as important to burning as the depth and packing ratio of fuel after logging. (The packing ratio is the ratio of fuel volume to the volume of the fuel bed.) The packing ratio for material less than 3 in (7.6 cm) averaged 0.062 on the residue-removed units and 0.030 on the conventional units. (The optimum packing ratio for combustion for this type fuel using Rothermel's model [1972] of fire spread was 0.009.) Thus, the packing ratio on the residue-removed units restricts combustion to a greater degree than on the conventional units.

Conventional utilization produced only slightly more material less than 3 in (7.6 cm) in diameter than did residue removal. On the conventionally logged units, however, a substantially greater percentage of residue was highly flammable needles than on the residue-removed units. After logging, material 0 to 0.2 in (0 to 0.5 cm) in diameter had decreased on both conventional and residue-removed units—probably because small materials had been crushed and churned into the forest floor.

Disruption of fuel continuity and exposure of mineral soil were greater on the residue-removed units than on the conventional units.

Duff, which averaged almost 1-in (2.5-cm) deep on all units, had an average bulk density of 8.7 ± 1.9 lb/ft^3 (140 ± 30 kg/m^3). Logging did not reduce the amount of duff, but did change its distribution.

Analysis and prescription.—Rate of fire spread and fireline intensity for the propagating flame front of a fire were estimated using the inventoried fuel data as inputs for the mathematical model of fire spread (Rothermel 1972). The model predicted that rate of spread after logging would be about 3 to 4.5 times greater

on the conventional blocks (fig. 5) than on the residue-removed blocks. Fireline intensity (heat from a 1-ft-wide cross section through the propagating flame front) was predicted to be about six times greater on the conventional blocks for any windspeed and fuel moisture for the first years (fig. 6).

Fireline intensity is probably the most useful characteristic of fire behavior for evaluating slash fuel hazard. At fireline intensities of 500 to 700 Btu's/ft, direct attack becomes ineffective and spotting begins to be a problem (Puckett and others 1977). At 1,000 Btu's/ft, crowning and serious spotting can be expected. Considering 500 to 700 Btu's/ft to represent an unacceptable hazard, figure 6 shows that for 1 to 2 years after cutting, conventional logging creates unacceptable hazards (Puckett and others 1979). After 3 to 5 years, hazard in conventional units falls to an acceptable level due to loss of needles and settling of slash. Figure 6 also shows a low hazard in the residue-removed units, even in the first years.

After the fuel assessment, a burning prescription was prepared. The primary objective of the burn was to reduce fuel hazard. Burning was to be carried out with a fire buildup index between 60 and 115, with an upper duff moisture content of 15 to 50 percent, and with a windspeed of less than 10 miles per hour.

Burning.—The plan was to burn the units in the fall of 1972. Unfortunately, as is common in that area, frequent storms during the late summer and fall prevented burning that year. In June of 1973, fuel conditions were reasonably dry and the decision was made to proceed with the burning. Spring or early summer burning is not normally done in the area, but the regeneration phase of the study would have been confounded by any further delay.

Departures from the prescription included burning in June after logging slash had overwintered. Fuel moistures were considerably higher than those prescribed because snowmelt had occurred only 2-3 weeks prior to the burn. This higher fuel moisture was offset to some extent by constant winds of more than 15 miles per hour. Further, needles in the slash had fallen to the ground and were compacted by winter snows. On the broadcast-burn units, prescriptions called for a fireline to be constructed with no jackpiling in the unit, but there were, in fact, windrows of slash on some edges of the uncut stand. Windspeeds exceeded those in the prescription, but not sufficiently to make the burn unsafe. Some scorching occurred, but this was due to excessively high windrowing of material pushed from the firelines on the perimeter of the units.

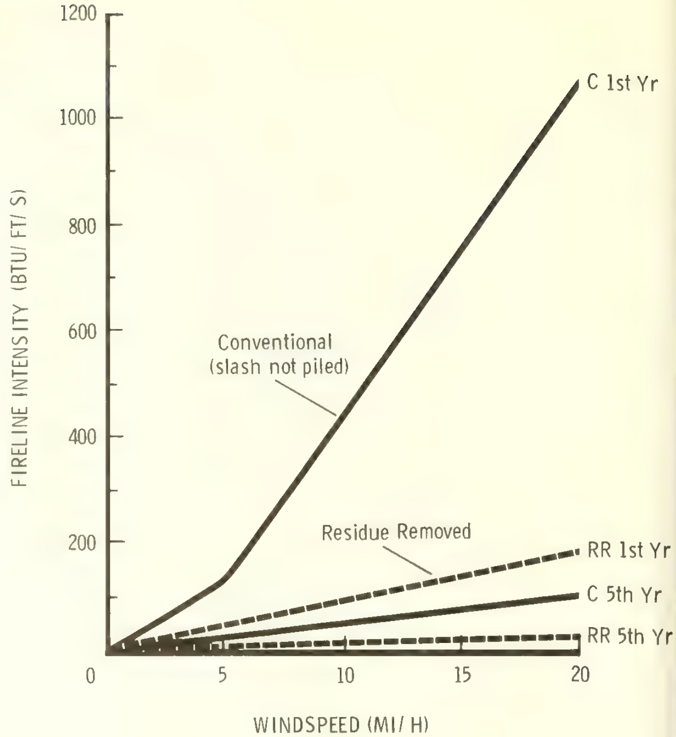


Figure 6.—Predicted fireline intensity by harvest method.

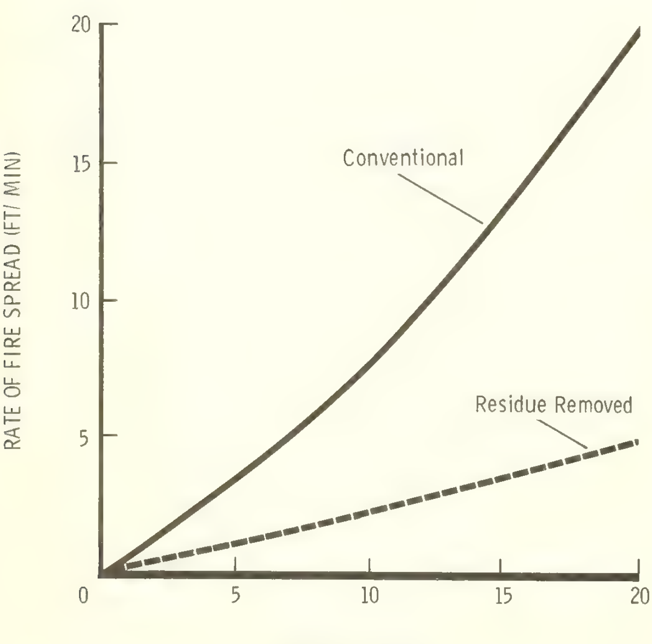


Figure 5.—Predicted rate of fire spread for logging residues, following conventional and residue-removed treatments.

The burning was conducted on a June evening between 1900 and 2200 hours. Ignition followed a pattern from the center of the edges of the units; a column was created, but the strong, steady breeze kept it tipped over on a 45-degree angle for most of the burning. Windrows burned hot and caused some scorching of the uncut timber. In the broadcast-burn sections, burning occurred readily when continuous fuels were present.

Following the burning, the volume of material larger than 3 in (7.6 cm) was estimated. On the broadcast burns, the planar intercept method was used. On the pile/burn units, 50-ft segments of piles were randomly selected and the size of all pieces was recorded for computing an estimate of the material remaining. Volume of woody material on the pile/burn units averaged about 42 percent of the preburn volume, and on the broadcast burns averaged about 66 percent of the preburn volume. The costs of burning were as follows:

	1971 dollars	1980 dollars
Broadcast, $/acre	13.81	24.72
Pile/burn, $/acre	7.70	13.78

Site Preparation and Regeneration

James E. Lotan

Clearcutting is the most practical silvicultural method for regenerating lodgepole pine (Tackle 1954; Lotan 1975b), but large amounts of residue left after logging leave the areas unsightly, create fire hazards, and impede forest management activities. Of particular concern initially is managing residues so as to encourage regeneration and growth of the new forest. In this study four postlogging treatments and three regeneration methods were tested.

Postlogging treatments.—On the two blocks logged to conventional utilization standards, slash was tractor piled and burned on two separate quarters of each and was broadcast burned on the other two quarters, as described earlier. Two quarters of each residue-removed unit were left "as is" following logging and chips were spread on the other two quarters. The map in figure 4 showed the location of these treatment in each unit.

Regeneration methods.—Each quarter block was further divided into thirds for the following three regeneration treatments: (1) auger-planting 2-0 lodgepole pine seedlings, 700 per acre (1 729/ha) in 18 in (45 cm) square scalped spots; (2) spot seeding of 12 to 15 lodgepole pine seeds on about 1,000 seed spots per acre (2 500/ha) after the spots (18 in [45 cm] square) were scalped free of competing vegetation (Lotan and Dahlgreen 1971); and (3) left for natural regeneration. The study area had primarily nonserotinous cones. Planting stock came from the Lucky Peak nursery near Boise, Idaho. Seeds for both the planting stock and the seed spots had been obtained from the upper Fish Creek drainage near the study site.

Planting was done in early June, and seeding in late June, 1973. Techniques used were standard procedures recommended by the Intermountain Regional Office. Planting stock was transported from snow-cache storage each day.

The study area was fenced to keep livestock out, and pocket gophers were effectively controlled with poisoning. However, large ungulates such as moose (*Alces alces* [Nelson]), elk (*Cervus canadensis* [Bailey]), and deer (*Odocoileus* sp.) frequented the area.

Regeneration costs.—Costs of regeneration (1971 and updated to 1980) were:

	Planting		Seeding	
	1971	1980	1971	1980
	Dollars per acre			
Broadcast burn	$122.89	$219.98	$75.33	$134.84
Pile/burn	133.48	238.93	61.12	109.40
Residue-removed	156.92	280.97	66.93	119.80
Chip spread	146.00	261.34	53.05	94.96

Poisoned grain for rodent control cost $3.00/acre in 1971 ($5.37 in 1980). Fencing cost $61.50/acre in 1971 ($110.08 in 1980).

The tree survival, growth, and vegetative development were measured periodically in years following regeneration. The techniques and results of these regeneration studies are discussed later in this report.

PRIMARY RESPONSES

This section describes the initial changes in the site that occurred in connection with harvest and posttreatment activities. Ultimately, effects of harvesting are reflected in the familiar components of the forest scene—vegetation, trees, and wildlife. But underlying and preceding these are the initial changes brought about from harvesting to the microclimate, biomass, and soil and water regimen.

Biomass and Cover

Prior to harvest there were 141 to 149 tons per acre (316 to 334 t/ha) of woody material on the site, including tree crowns (duff excluded). About 90 tons per acre (202 t/ha) were removed as saw logs, and the remaining residues were burned, removed, or chipped and spread back over the site.

The amount of woody material remaining after harvest and residue treatment ranged from about 19 tons per acre (42 t/ha) on the residue-removed units to about 68 tons per acre (152 t/ha) where residues were chipped and spread back on the site. In the pile/burn treatment, residues were reduced as much as on the residue-removed treatment, but on the broadcast burns, more material remained as charred or lightly burned pieces.

The woody material weights and the percentage of change from preharvest to posttreatment are as follows:

	Pre-harvest		Post-treatment		Percent change
	Tons/acre	*(t/ha)*	*Tons/acre*	*(t/ha)*	
Residues-removed	141	(316)	19	(42)	−87
Residues chipped and spread	141	(316)	68	(152)	−52
Conventional, broadcast burn	149	(334)	34	(76)	−79
Conventional, pile/burn	149	(334)	20	(45)	−87

Measurements and estimates of understory vegetation were made in undisturbed stands and after harvesting. Before harvest there was about 400 lb per acre (448 kg/ha) of understory vegetation, most of which was destroyed in logging. After harvest and residue treatment, understory vegetation was estimated to be 50 lb per acre (56 kg/ha).

Prior to harvest, the ground cover in undisturbed stands was predominantly needles, woody material, grass, and forbs. Following harvest (prior to spreading chips or burning), grass and brush cover were virtually eliminated and mineral soil increased by 30 to 40 percent (table 2). Woody material cover also increased by about 10 percent. After burning and chip-spreading were completed, the total ground cover in those treatments was estimated as follows: chip-spread, 100 percent; broadcast burn, 80 to 90 percent; and pile/burn, 47 percent.

In the pile/burn areas the logging slash was pushed into windrows approximately 20 ft (6 m) wide. After burning, these windrows ranged from about 2 ft to 5 ft (0.6 to 1.5 m) in height. A few large round piles were somewhat deeper. Piles consisted of unburned wood plus a large amount of earth that was pushed into the pile. This is not considered good practice. These burn piles occupy about 18 percent of the total area of the units, based on photo measurements. About 500 ft^3 per acre (35 m^3/ha) of woody material 3-in (7.6-cm) diameter and larger remained in the areas between the piles.

Table 2.—Ground cover before and after harvest by treatment

Cover	Conventional		Residue-removed	
	Pre-harvest	Postharvest	Pre-harvest	Postharvest
	Percent			
Mineral soil	0.7	28.7	2.3	42.5
Needles	51.0	40.5	48.0	26.2
Woody	18.8	29.2	21.2	31.0
Grass	13.3	.5	21.9	.2
Brush	16.1	0	5.5	0
Total (rounded)	100	100	100	100

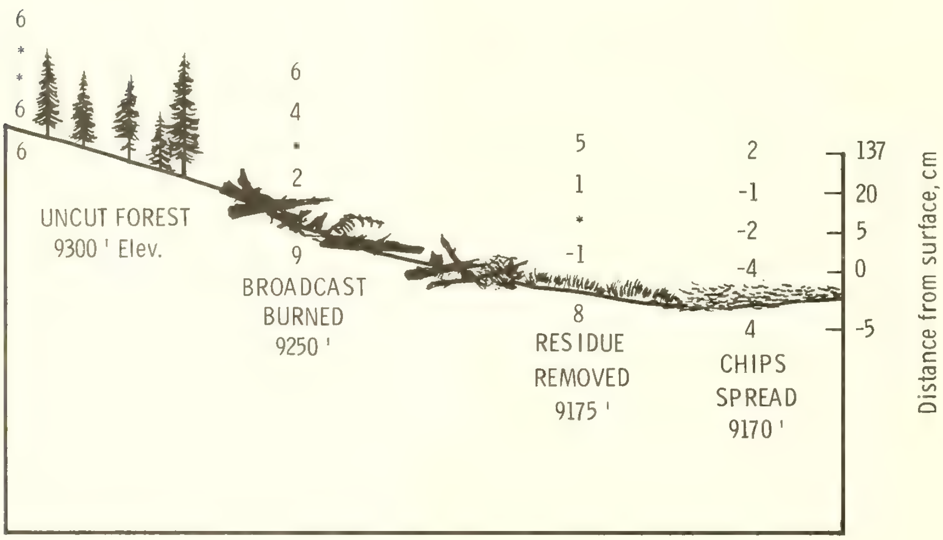


Figure 7.—Low temperatures recorded for July 15, 1979, at units 1 and 2.

Microenvironmental Effects

Roger D. Hungerford

A preliminary analysis of data in 1978 suggested that temperatures at or near the surface might influence seedling survival and growth. Beginning July 12, 1979, air temperature and soil temperature were recorded hourly at units 1 and 2 for chip-spread, residue-removed, and broadcast-burn treatments, and in the uncut forest. Net radiation was recorded hourly for the chip-spread treatment. On August 2, the recording systems were disabled by a bear but about 3 weeks' data were obtained.

Temperatures were recorded at the surface, below the surface (2, 5, 10, 20, and 40 cm), and above the surface (5, 20, and 137 cm). Because of some topograhic variations, both air drainage and residue treatment may affect temperature, and it was not possible to separate these. Nevertheless, the temperatures recorded can be used in analyzing seedling survival and growth.

Figure 7 shows a profile across the site for July 15, and illustrates typical low-temperature relationships. The uncut forest and the broadcast burn-treatment, both of which were upslope, had slightly warmer temperatures than did the residue-removed and chip-spread treatments, which were at a lower elevation in the particular unit measured.

On all treatments, temperatures were coldest at the surface, progressively warmer at distances above the surface, and warmest below the surface.

Both high and low temperatures have been reported as causing lodgepole pine seedling mortality. Cochran and Bernsten (1973) reported that lodgepole pine seedlings can tolerate low growing season temperatures of −9° C, but first-year seedlings are particularly susceptible. By mid-growing season −8° C caused 70 percent mortality and −5° C caused 20 percent mortality. High temperatures of about 52° C caused death of plant cells (Hare 1961; Baker 1929), but Lotan (1964) reported seedlings can survive surface temperatures of 60° C for short periods because temperatures of cambial cells do not rise above 52° C.

At the study site only the chip-spread treatment had temperatures −8° C or colder: this low was reached on 20 percent of the nights, for an average duration of 0.65 hour.

The −5° C threshold was reached on both the chip-spread and residue- removed treatment, and freezing temperatures (< 0° C) were reached in all harvested treatments but not in

Table 3.—Frequency and duration of temperatures < 0° C and ≤ -5° C on units 1 and 2 in summer 1979, by treatment and height above surface

Frequency

Treatment	Percent of days < 0° C				Percent of days ≤ -5° C			
	Surface	5 cm	20 cm	137 cm	Surface	5 cm	20 cm	137 cm
Chip-spread	85	75	60	5	45	20	5	0
Residue-removed	65	45	20	0	10	—	0	0
Broadcast burn	10	—	0	0	0	—	0	0
Uncut	0	—	—	0	0	—	—	0

Duration

Treatment	Mean h/day < 0° C				Mean h/day ≤ -5° C			
	Surface	5 cm	20 cm	137 cm	Surface	5 cm	20 cm	137 cm
Chip-spread	5.3	3.0	1.8	0.05	1.6	0.6	0.05	0
Residue-removed	3.0	—	.8	0	.5	—	0	0
Broadcast burn	.2	—	0	0	0	—	0	0
Uncut	0	—	—	0	0	—	—	0

the uncut forest. Low temperatures and their duration are summarized in table 3.

Surface temperatures were low enough to expect substantial seedling mortality on the chip-spread treatment and some mortality on the residue-removed treatment. Actual survival and growth of seedlings support these predictions. In five growing seasons, planted seedlings suffered 76 percent mortality in the chip-spread treatment and 46 percent mortality on the residue-removed treatment in unit 1.

Topography as well as treatment may have contributed to low temperatures in units 1 and 2. In unit 4, mortality for chip-spread was about 30 percent and for residue-removed, 20 percent. This unit was not continually monitored for temperature, but all treatments were on a slope that would not trap cold air, and low threshold temperatures were less likely. Survival and growth of seedlings are discussed in more detail in later sections.

Surface temperatures of 58° C were recorded on the residue-removed and broadcast-burn treatments, and 53° C on the chip-spread treatment during the period. On all three treatments, temperatures of 50° C or higher were sustained 2 hours or more for at least some of the days. Such temperatures would not likely cause significant damage or mortality to the planted seedlings.

Net radiation was higher above the broadcast-burn and residue-removed treatments than above chip-spread or pile/burn treatments. This indicates greater reflectivity on the latter treatments, and could increase leaf temperatures on seedlings. This potentially could increase transpiration.

Soil Properties and Nutrients

Norbert V. DeByle

For more than 5 years, scientists sampled physical and chemical soil parameters, soil solution chemistry, overland flow and erosion, vegetative cover and biomass, and associated parameters on the study area to evaluate treatment effects on soil fertility, site quality, erosion, and water quality. Soil samples for chemical analyses were taken at the initiation of the treatments and again 5 years later (DeByle 1980). Samples were analyzed for pH, cation exchange capacity, nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), boron (B), zinc (Zn), iron (Fe), and sodium (Na).

The physical soil parameters, vegetative cover, runoff, and erosion were sampled and measured in 1973, 1975, and 1977 (Packer and Williams 1980). In each of these years, 60 infiltrometer plots (48 on the clearcut tracts and 12 in the adjacent unlogged forest) were treated with a rainfall simulator that applied water at a constant rate of 8.2 cm/h (3.2 in/h). Vegetal characteristics and soil cover were measured with a point analyzer on 100 points within each plot. Soil solution samples were withdrawn from depths down to 4 ft (1.2 m) at several locations and times during each growing season (Hart and others 1981). These solutions were analyzed for contents of K, Ca, Mg, Na, nitrate-N, phosphate, total phenols, and electrical conductivity.

Five planted and five seeded lodgepole pine trees were taken from each quadrant of each unit in 1977 and dissected into five components (DeByle 1980). Each component was weighed and analyzed for contents of N, P, K, Ca, Mg, Zn, Fe, B, Na, and ash.

SURFACE ORGANIC LAYER

Harvesting and slash disposal left markedly different physical conditions on the surface layer. After treatment the amounts of litter and debris less than 1.2-in (3-cm) diameter remaining on the soil surface, and thus making up the A_0 horizon were:

	Litter weight		Litter depth	
	Lb/acre	*(kg/ha)*	*In*	*(cm)*
Uncut forest (control)	31,667	(35 494)	1.02	(2.6)
Broadcast burn	31,220	(34,995)	.71	(1.8)
Pile/burn (under piles)	28,537	(31,985)	.67	(1.7)
Pile/burn (between piles)	29,641	(33,222)	.51	(1.3)
Residue-removed	37,662	(42,213)	.94	(2.4)
Chip-spread	161,124	(180,592)	46.1	(11.7)

The quantity and depth of litter on the chip-spread treatment was highly significantly different from all others.

The nutrient content of the surface organic layer also

Table 4.—Nutrient content of the surface organic (A_0) horizon

Nutrient	Year	Uncut forest	Broadcast burn	Pile/ burn (under)	Pile/ burn (between)	Residue-removed	Chip-spread
		Lb/acre (kg/ha)					
Nitrogen	1972-73	412 (462)	311 (349)	115 (129)	309 (346)	273 (306)	—
	1977	450 (504)	398 (446)	257 (288)	272 (305)	409 (458)	508 (569)
Phosphorus	1972-73	30 (34)	50 (56)	46 (52)	28 (32)	37 (41)	—
	1977	35 (39)	34 (38)	28 (32)	24 (27)	34 (38)	69 (78)
Potassium	1972-73	66 (96)	105 (118)	107 (120)	70 (79)	118 (132)	—
	1977	61 (68)	59 (66)	45 (51)	45 (50)	65 (73)	148 (166)
Calcium	1972-73	156 (175)	284 (318)	310 (347)	115 (129)	168 (188)	—
	1977	299 (335)	374 (419)	320 (359)	196 (220)	267 (299)	408 (457)
Magnesium	1972-73	54 (61)	94 (105)	96 (108)	80 (90)	87 (98)	—
	1977	73 (82)	75 (84)	57 (64)	54 (61)	69 (77)	165 (185)
Sodium	1972-73	—	—	—	—	—	—
	1977	4 (5)	4 (4)	4 (4)	3 (3)	4 (4)	10 (11)

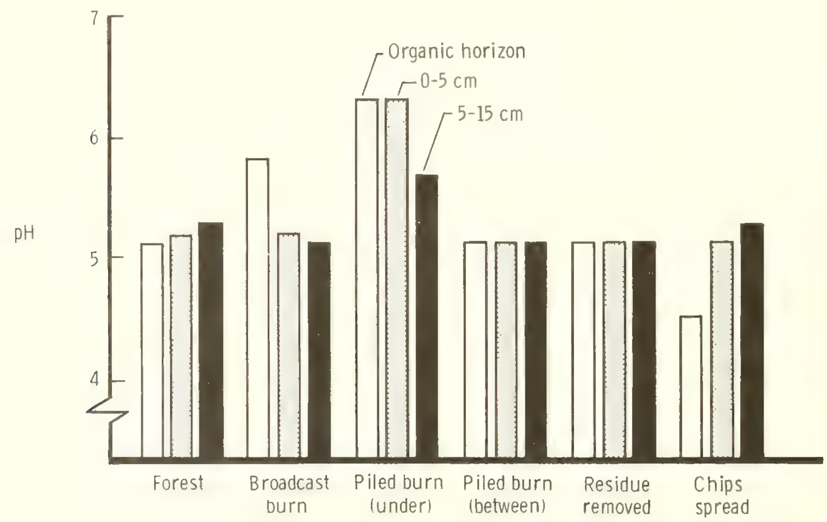


Figure 8.—Soil pH 5 years after treatment.

changed as a result of treatment. Over the 5-year timespan there was an increase in the N and Ca contents and a decrease in the K and Mg contents of this horizon (table 4). Even though chips had a lower concentration of most elements than did the litter in the uncut forest, their large volume on the chipped-returned site, plus the residual litter beneath, resulted in a larger quantity of every nutrient on this treatment than on any other. After 5 years, total N content was least (228 kg/ha) under burned piles; K content was lowest (50 kg/ha) both under and between piles. Phosphorus seemed unaffected by treatments. Residue removal as well as burning the slash initially increased the contents of K and Mg in the surface organic layer by approximately one-third. But, 5 years later these had returned to near the values found in the undisturbed forest, 68 and 82 kg/ha, respectively.

MINERAL SOIL

The pH of each layer of soil sampled in 1977, 5 years after treatment, is illustrated in figure 8 (DeByle 1980). Mineral soil pH under all but one of the treatments was essentially the same, averaging 5.2. Under the burned piles it was markedly higher—6.4 in the 0- to 5-cm depth and 5.7 in the 5-to 15-cm depth. The pH of the organic surface horizon was less uniform. It was 5.8 and 6.4 in the ash-litter-duff mixture on the broadcast-burn and pile/burn treatments, respectively, still reflecting the changed physical conditions and the release of cations triggered by burning 5 years earlier. In contrast, the slowly decomposing chip mulch had a pH of 4.6, more acidic than the underlying mineral soil.

The year after burning, in 1973, the pH at various soil depths under the burned piles was: A_0 horizon 7.2; 0 to 5 cm, 6.5; and 5 to 15 cm, 5.3. In the areas broadcast burned 2 months before sampling, pH was 6.2, 4.8, and 5.0 at the same depths. Burning immediately changes the pH of the

Table 5.—Percentage of organic material in mineral soil

Treatment	Depth and year			
	0-5 cm[1]		5-15 cm	
	1972-73	1977	1972-73	1977
Forest	6.0	5.2	3.4	2.2
Broadcast burn	7.2	5.9	3.5	2.4
Pile/burn (under)	6.9	4.1	4.4	2.8
(between)	7.1	4.6	3.7	2.6
Residue-removed	6.6	5.9	4.5	2.2
Chip-spread	7.1	8.6	4.6	2.2

[1]Average of Packer and William (l980) and DeByle (l980) observations.

organic surface layer. Leaching of soluble material from that layer by subsequent precipitation later raises the pH of the mineral soil beneath. Those changes were present a year after burning and have remained for several years. Other treatments did not significantly change mineral soil pH.

The organic matter content of the 0- to 5-cm layer of undisturbed forest soil ranged between 5 and 6 percent (table 5). In the 5-to 15-cm layer it was half this concentration. Treatments changed the content of organic matter in the surface 5 cm. In 1977 the highest organic matter content, 8.6 percent, occurred where the logging residue had been returned as a mulch of chips. The lowest organic matter content, 4.1 percent, occurred beneath burned windrows. During the 4-year period the organic matter content of the mineral soil increased where the residue treatments did not involve burning and decreased where burning was part of the disposal treatment. Disturbance caused by logging, thus breaking up fine organic debris in the A_0 horizon and incorporating it into the mineral soil beneath, likely caused the initial increase in organic matter content. Burning and decomposition of organic material in the soils no doubt resulted in the later decline on most treatments. During this time, a decrease would be expected because new plant growth added little organic matter to the soil on these clearcut sites.

As the content of organic matter varies, so will the content of total nitrogen. Total N supply in 1977 in the upper 15 cm of mineral soil varied from 2 000 kg/ha under the undisturbed forest to more than 2 600 kg/ha under the broadcast burn (DeByle 1980). Per unit of depth, there was almost twice as much N in the 0- to 5-cm layer of soil than in the 5- to 15-cm layer. The quantity of N available for plant growth has very limited relationship to total supply. Instead, available N varies with nitrification rates and, hence, depends upon microbiological activity. This is discussed in later sections. (See also Schmidt and Lotan 1980; Jurgensen 1980.)

Available P was almost twice as abundant in the upper 15 cm of mineral soil 5 years after logging than it was in the undisturbed forest. The largest quantity (64 ppm) was found under the chip mulch, with the next largest amount (58 ppm) under burned piles. That between burned piles, in contrast, was not significantly different than the forest. Extractable K was greatest (0.63 meq/100 g) in 1977 in the mineral soil under the burned piles of debris. The mineral soil in the forest had only 0.45 meq per 100 g of K. Extractable Ca was slightly increased by the logging operation. The soil under the burned piles contained twice as much Ca (9.4 meq/100 g) as did the undisturbed forest. Extractable Mg quantity followed the same pattern. Zinc was more than twice as concentrated (7.4 ppm) under burned debris piles than on any other treatment. Broadcast-burned sites were also slightly elevated in Zn concentration. The most Fe was found under chip spread (445 ppm), where it was twice as concentrated as it was in the undisturbed forest. The soils under burned piles had 304 ppm Fe, the next greatest concentration.

The cation exchange capacity of the surface 5 cm of mineral soil averaged 18.63 meq per 100 g and that of the 5- to 15-cm layer averaged 15.27 meq per 100 g. In 1977, four cations (K, Na, Ca, and Mg) occupied a bit less than one-half of this capacity in the undisturbed forest, about half under four of the treatments, and nearly three-fourths of the total cation exchange capacity under the burned piles. This indicates that nutrients released by decomposition and burning are, in fact, being caught and held within the soil mantle.

The bulk density of the surface 5 cm of soil in 1973 was greatest where the chip mulch had been recently applied (Packer and Williams 1980). This was probably caused by compaction from tractors used to spread the chips. The next highest bulk densities occurred between windrows, also probably related to tractor compaction. In 1977, the highest bulk densities were found between windrows and the lowest in the unlogged forest. In the interim, soil bulk densities improved (decreased) on the residue-removed utilization units. In contrast, bulk densities remained high under the pile/burn treatment.

Total porosity of the soil is the converse of bulk density. The more porous the soil, the lower its bulk density. Also, other factors being equal, the greater will be its capacity for infiltration and percolation of water. By 1977, the greatest porosity was encountered in the unlogged forest and the lowest between windrows, the very sites where bulk density was lowest and highest, respectively (fig. 9).

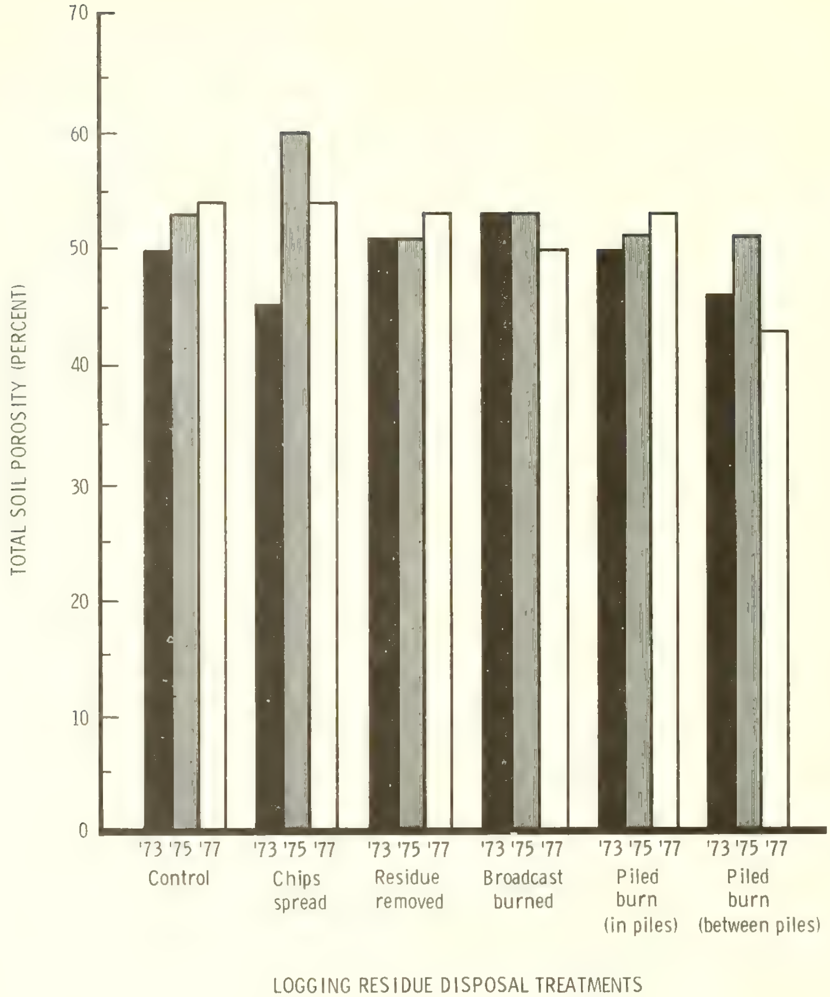


Figure 9.—Total porosity of the surface 2 inches of soil associated with various residue treatments on lodgepole pine clearcuts.

SOIL SOLUTIONS

From 1972 through 1977, more than 600 samples of soil solutions from 44 tubes under 6 treatments were analyzed (DeByle 1980; Hart and others 1980). The average concentrations of nutrients in the soil solutions under the control (uncut forest) and the treatment yielding the highest concentrations (under the burned piles) are shown in the following tabulation:

Nutrient	Forest	Pile/burn (under)
	Mg/liter	*Mg/liter*
Potassium	0.6	2.0
Sodium	1.4	2.2
Magnesium	.7	3.3
Calcium	2.6	11.9
Nitrate-nitrogen	.1	4.4

Potassium concentrations increased under the chip mulch and under both burning treatments. Sodium increased, too, especially under burned piles. Higher concentrations of magnesium were observed under both the chip-spread and the burns. Levels of calcium increased and persisted under all treatments. Most residue disposal methods produced greatly increased concentrations of nitrate-nitrogen. Increases varied from twofold to a hundredfold, with some samples approaching a concentration of 10 mg/liter. Clearcutting alone interrupts the nutrient cycle and may increase nutrient concentrations in the soil solution. Leaching of logging debris also contributes nutrients. Conditions present after an intense fire in large concentrations of fuel, such as beneath windrows, further elevate concentrations of some nutrients.

Nutrients held in the biomass that remain on the site after harvest are either slowly released through decomposition, or rapidly released or converted to a soluble form by burning. Some of these released nutrients are lost from the site; some are held within the mineral soil to be removed by developing vegetation. As the forest develops and matures, nutrient cycling again will occur much as it did in the stand that was harvested. Prior to establishment of a complete vegetative cover, we can expect greater nutrient losses in runoff waters. Most losses occur immediately after treatment, especially if burning is applied. The concentration of nutrients in the soil solutions are indicative of what might be lost from the site during the first 5 years. These in-

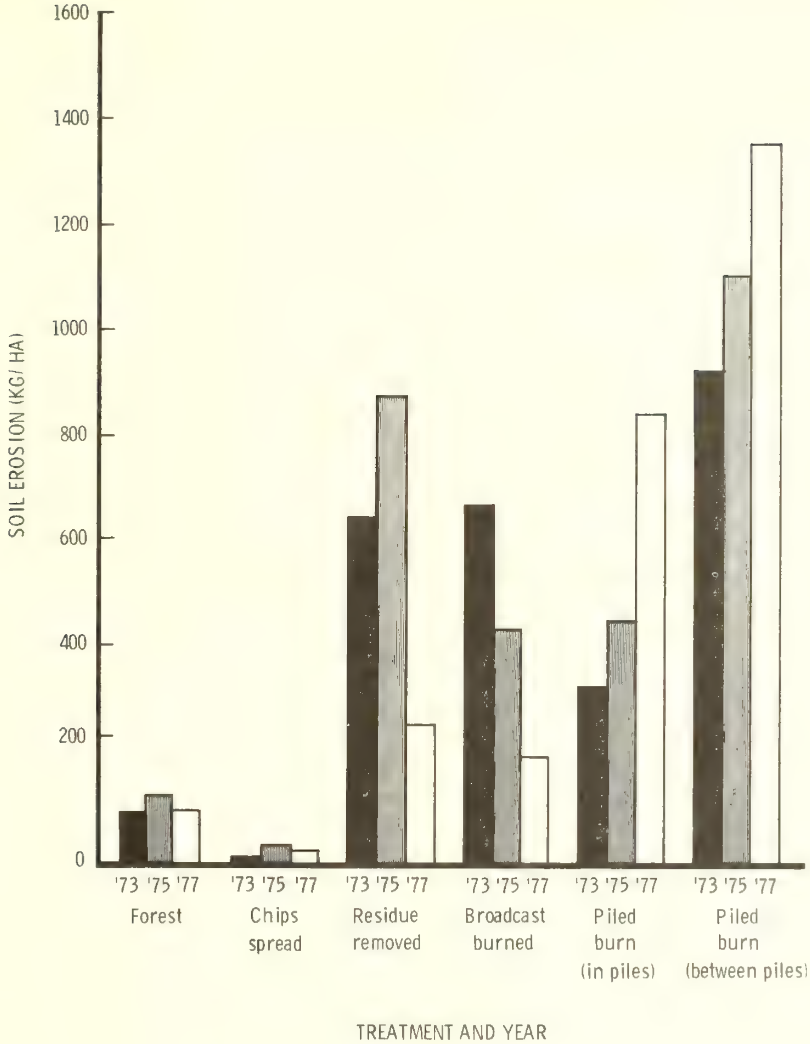


Figure 10.—Soil erosion infiltrometer plots on all treatments in 1973, 1975, and 1977.

creased nutrient levels most likely will diminish to those levels found in the uncut forest within the next 5 years. Nitrate-nitrogen may be an exception—the increased nitrification that perhaps is associated with herbaceous vegetation may occur until the forest becomes fully reestablished. Until that time, increased nitrate levels may exist in the soil solutions. With the exception of increased nitrates, none of the treatments produced nutrient changes in the soil and water that should concern the manager. Some of the highest nitrate concentrations measured in the soil solution, if they reached the ground water or stream without further dilution, would be considered a pollutant in a public water supply where the maximum concentration allowed is 10 mg/liter.

Total phenol concentrations in the soil solution ranged from practically none under undisturbed conditions to 0.666 ppm under chip-spread and to 0.188 ppm under the residue-removed treatment during the first year. Thereafter they declined markedly. Such organic compounds appear to readily leach from finely divided conifer debris, especially chips. During the first year they were found in the soil solution under some treatments in concentrations that could reduce plant growth. Phenolics released from plants are believed to be a cause of allelopathy (Fisher 1980).

Phenolic compounds flushed into the soil solution from the residue-removed units, particularly from under the chip mulch, are a potential pollutant. This flush occurs only during the first year or two after treatment, but the concentrations far exceeded allowances for public water supplies (0.001 ppm). Also, the phenolics may have contributed to the stunted seedling growth on the chip-spread area. Both possibilities should concern the forest manager; however more research is needed to determine if our concerns are valid.

SURFACE HYDROLOGY AND SOIL STABILITY

Surface runoff (overland flow) from the infiltrometer plots was least on the chip-spread treatment. Here only 20 to 25 percent of the rainfall applied was collected as surface runoff (Packer and Williams 1980). Although there was wide variation among the years of sampling, by 1977 the broadcast-burned sites had a similarly small amount of overland flow. In both instances, runoff was about half the amount produced in the unlogged forest. Largest amounts of overland flow occurred between

Table 6.—Soil microbial populations in the surface 0- to 5-cm mineral soil layer[1]

Year	Control	Chip-spread	Residue removed	Burn treatments: Broad-cast	Burn treatments: Piled: Between	Burn treatments: Piled: Under
Bacteria (X10[6])						
1972	3.2	—	10.9	—	—	—
1976	12.0	4.1	4.7	10.4	3.0	2.6
Streptomyces (X10[5])						
1972	7.5	—	20.4	—	—	—
1976	4.2	1.2	2.0	6.0	2.0	5.2
Fungi (X10[5])						
1972	2.3	—	9.0	—	—	—
1976	2.8	1.2	3.5	2.7	0.4	2.3

[1]From Skujins, see text footnote 2.

windrows where residues as well as some vegetation and soil had been removed by dozer piling. Here two-thirds of the water applied was caught as surface runoff; only one-third infiltrated.

The amounts of soil erosion measured on these infiltrometer plots for the 3 years of record are shown in figure 10 (Packer and Williams 1980). In each year, less than 45 kg/ha eroded from the chip-spread treatment, much less than from the unlogged control sites. The largest amounts of erosion—in excess of 1 340 kg/ha—occurred between windrows in the pile/burn treatment. With the exception of areas mulched with chips, erosion was least where residue was broadcast burned.

From the standpoint of overland flow and soil erosion, the most effective residue treatment is chipping and respreading these chips as a protective mulch. Nevertheless, this treatment has serious disadvantages—almost complete suppression of vegetation and elimination of natural forest regeneration for at least 5 years and perhaps up to 20 years after application. The most adverse overland flow and erosion were encountered where residue was dozer-piled and burned. Recovery rates here were slow during the first 5 years, but the forest will probably become reestablished on this treatment faster than on any other. A closed-canopy lodgepole pine forest again will provide adequate watershed protection. One of the least detrimental residue disposal treatments in terms of watershed condition, performance, and speed of recovery during the first 5 years is residue-removed treatment. On this treatment, however, herbaceous vegetation may have to supplant the much more slowly developing lodgepole pine forest for watershed protection during the next several decades.

From the standpoint of economics and practicality, broadcast burning after conventional clearcutting provides fairly rapid return to preharvest conditions and suitable forest regeneration. In general, impaired watersheds do not rapidly recover at the high altitudes and short growing seasons that characterize these forests. Sites where the vegetation and soil mantle have been drastically disturbed by mechanized equipment recover more slowly than similar sites where residue disposal did not disturb the forest floor.

Soil Microorganisms

Martin Jurgensen, Alan E. Harvey, and Michael J. Larsen

Soil microflora influence the continued productivity of the forest ecosystem. The activities of these organisms are strongly affected by various silvicultural or logging programs (Jurgensen, Larsen, and Harvey 1979). Timber harvesting directly influences soil microorganisms by removing organic matter from a site as logs or pulpwood, and by postlogging site preparation techniques such as burning and soil scarification. Organic matter decomposition is affected by soil chemical and physical changes following these operations (Harvey and others 1976). The decomposition of organic matter, both in the litter layer and mineral soil, by soil microorganisms is a key factor in the cycling of many soil nutrients. Nitrogen availability is especially sensitive to changes in microbial activity. Nearly all of the nitrogen in forest soils is present in organic form (Jurgensen and others 1980). Consequently, any study on the environmental impact of harvesting and residue utilization programs must consider effects on soil biological properties.

With the cooperation of various groups of Forest Service and university scientists, the numbers and activities of soil microorganisms were monitored on the study plots. Populations of bacteria, streptomyces and fungi, carbon dioxide evaluation rate (respiration), dehydrogenase and protease activity, and the levels of ammonium and nitrate were measured in the soil before and at various times after the site treatments. Details of the sampling design and methodology are given by Skujins.[2] An estimate of nonsymbiotic nitrogen fixation rates was made in July 1978 using the acetylene reduction technique described by Larsen and others (1978). Five soil cores were taken from each plot using an impact sampler (Jurgensen and others 1977). Chip-spread layer and chip piles left on the site were also sampled for nitrogen-fixing activity and chemical composition. In addition, the number of mycorrhizal root tips in the uncut control stand was compared to such root tips in other timber types in the Northern

[2]Skujins, John. Effect of modified slash disposal practices on the biochemistry of soils. Office report, study FS-INT-1203. Missoula, MT: Forestery Sciences Laboratory; 1977.

Rocky Mountain region. Mycorrhizal root counts were taken from 50 soil cores using the methods described by Harvey and others (1979).

SOIL MICROBIAL PROPERTIES

Populations of soil microorganisms responded to logging and the resulting opening up of the stand in the year (1972) following harvesting (table 6). Three to four years later, however, numbers were similar among the various postharvesting treatments. Bacteria populations generally appeared lower in the treated plots as compared to the uncut control, but a large variation in counts coupled with a limited sample precluded meaningful statistical analysis.

The effects of timber and residue removal on soil biochemical activities are illustrated by the respiration rates as shown in table 7. No pattern of response was evident among site treatments, although year-to-year differences were apparent. Similar results were found with the dehydrogenase and protease enzyme assays.

NITROGEN MINERALIZATION

In contrast to microbial population and biochemical results, decided treatment effects were noted in soil nitrogen transformations. Soil nitrate levels were uniformly low in the uncut stand during the 5-year study period. This contrasts with the higher nitrate concentrations found in all treated plots (table 7). The greatest nitrate responses were associated with broadcast burning and woodchip spreading in the year following treatment. Increased soil nitrate levels were still found in the broadcast-burn sites 3 years after the fire. High nitrate concentrations were also found in subsurface water samples by Hart and DeByle (1975) following the broadcast burn.

An inhibition of nitrification was evident in the soil beneath the slash piles, at least for the first year after they were burned. By the end of 3 years, however, appreciable amounts of soil nitrate were being produced. Hart and others (1981) found the highest nitrate concentrations in the subsurface water samples beneath the burned slash piles.

Soil ammonium concentrations varied considerably over the 5-year study period. Other than a sizable increase following burning, no discernible ammonium/treatment effects were evident (table 7). Nevertheless, similar to the biochemical assays, ammonium level fluctuated from year to year, particularly in 1976.

Increased soil nitrogen mineralization frequently occurs following timber harvesting, particularly if associated with a burning treatment (Mroz and others 1980). Such fire-related changes in microbial activity are attributed to the release of available carbon, ammonium, and mineral nutrients from the burned organic matter, and to a resultant decrease in soil acidity. Increased soil nitrogen mineralization rates reported on cut but unburned sites are likely due to more favorable soil moisture and temperature regimes, or to a removal of mycorrhizal fungal inhibition on soil microorganisms (Gadgil and Gadgil 1978; Wells and others 1979).

NITROGEN FIXATION

The microbial conversion (fixation) of inert atmospheric N_2 into usable forms is an important process in the replacement of nitrogen lost from a site due to timber harvesting or fire (Jurgensen and others 1980). Because most nitrogen-fixing organisms require organic substrates as energy and carbon sources, their activity would likely be favored in soil organic layers. Such an effect was shown in this study by the high nitrogen-fixation rates in the woodchip layer (table 8). Overall, nitrogen-fixation rates were highest in the uncut control stand, perhaps because of a more favorable soil climate or because of the activity of nitrogen-fixing microorganisms around plant roots (rhizosphere effect).

Table 7.—Effect of site treatment on respiration rates, and nitrate and ammonium concentrations in the surface 0- to 5-cm mineral soil layer[1]

Year	Control	Chip-spread	Residue removed	Burn treatments: Broadcast	Burn treatments: Piled, Between	Burn treatments: Piled, Under
Respiration			*Moles CO_2/gm of soil/minute*			
1972	[2](203)	—	91	—	—	—
1973	68	74	42	85	16	44
1974	54	40	24	24	23	10
1976	20	21	21	12	7	19
Nitrate			*Mg/liter*			
1972	(1.1)	—	0.6	—	—	—
1973	.6	2.2	1.7	5.3	(8.7)	(0.7)
1974	.6	11.6	3.0	22.0	9.6	.7
1976	.4	.3	2.0	10.3	.4	6.3
Ammonium			*Mg/liter*			
1972	1.1	—	2.3	—	—	—
1973	7.2	3.7	9.4	43.3	7.6	17.8
1974	11.2	5.8	5.4	14.5	2.1	6.1
1976	61.0	13.4	36.8	28.2	16.3	18.8

[1]From Skujins, see text footnote 2.
[2]Parentheses indicate value based on only one sampling during the growing season. Other values based on three sample collections.

Table 8.—Soil N-fixation rates as affected by site treatment

Soil strata	Control	Broadcast burning	Residue-removed	Chip-spread
	Grams N fixed/gram of soil/day ($X10^{-9}$)			
Surface organic layer (O_2)	2.1	0	0	[1]70.8
Decayed soil wood (O_3)	35.9	8.2	17.6	[2]
Mineral soil 0 to 5 cm	2.7	.7	.9	.9
5 cm to core bottom	.8	< .1	.2	.1

[1]Average value of nitrogen fixation in woodchip layer.
[2]Due to the presence of the chip layer decayed soil wood could not be located and sampled.

Table 9.—Amounts of N fixed per hectare per day as affected by site treatment

Soil strata	Control	Broadcast burning	Residue-removed	Chip-spread
	Grams			
Surface organic layer (O_2)	0.1	0	0	[1]11.3
Decayed soil wood (O_3)	0.2	0.1	0.1	[2]
Mineral soil 0 to 5 cm	2.1	.6	.7	.7
5 cm to core bottom	2.0	.2	.5	.3
Total	4.3	.8	1.3	12.3

[1]Average value of nitrogen fixation in woodchip layer (table 10).
[2]Due to the presence of the chip layer decayed soil wood could not be located and sampled.

When the weight/volume relationship of each soil fraction is used to calculate total amounts of nitrogen added to each site, a different perspective is obtained (table 9). Even though the nitrogen-fixing rates were much lower in the mineral than in the organic soil layers, the greatest nitrogen gains occurred in the mineral horizons. This is due to the high mineral/organic ratio in this soil. The only exception was in the chip-spread treatment, which had appreciable N gains in the chip layer.

These results indicated that timber harvesting reduced the amount of nitrogen added to these sites by nonsymbiotic nitrogen fixation, especially when a postharvest burning treatment was used. If it is assumed that in this high elevation soil the nitrogen-fixing microflora is active for only 100 days per year, less than 0.25 kg per ha per year of nitrogen would be added to the burned sites, and only 0.5 kg per ha per year to the uncut control. This compares with nitrogen gains of over 2 kg per ha per year in an uncut, highly productive northern Idaho cedar-hemlock timber type (Jurgensen and others 1980). Although these nitrogen additions are quite small on an annual basis, the significance over a stand rotation of 150 to 200 years would be appreciable. Nitrogen-fixation rates would likely increase as the stand becomes reestablished, but the length of the recovery period is unknown.

Symbiotic nitrogen-fixing plants, such as *Ceanothus, Alnus, Lupinus,* and *Astragalus* are also potentially significant sources of nitrogen on these sites. The occurrence and activity of these plants in Northern Rocky Mountain forest ecosystems appear to be small in most older stands, but may be significant following stand reestablishment (Jurgensen, Arno, and others 1979). Several species of lupine were the only nitrogen-fixing plants present on the study site prior to most residue treatments (Schmidt, personal communication). Lupines have been found to respond to burning treatments in Wyoming aspen stands (Bartos and Mueggler 1979). Whether they do the same in lodgepole pine following prescribed burning or other postharvesting practices remains to be seen.

The nitrogen gains associated with the woodchip treatments were higher than expected (table 10). Nitrogen-fixing activity was, by far, the greatest in the chip piles. In the chip-spread treatment nitrogen gains were greater in the chip layer closer to the mineral soil than near the surface. Such a nitrogen fixation/depth relationship is likely due to the insulating properties of the chips, which maintain a favorable moisture and temperature regime for microbial activity. A similar trend is also shown in the woodchip decay pattern, as indicated by lignin and carbohydrate levels (table 11). The greater the depth in the chip layer, the greater the loss of wood carbohydrates and a proportional increase in the more decay-resistant lignin component. Because the woodchips have a high carbon/nitrogen ratio, it is unlikely that much of the nitrogen fixed in the chip layer would be available for immediate plant use. As the decay process continues, however, this added nitrogen would slowly be released and used by the trees later in the rotation.

ECTOMYCORRHIZAE

The development of a viable mycorrhizal fungi/tree root association is an important link in maintaining stand productivity. Soil moisture, temperature,and organic matter levels influence the activity of ectomycorrhizae in Northern Rocky Mountain timber types (Harvey, Larsen, and Jurgensen 1980).

Table 10.—Nitrogen fixation associated with woodchip decay

Chip treatment	N fixed/gram dry wood/day	N fixed/hectare/day[1]
	Grams X10^{-9}	*Grams*
Spread		
Surface 5 cm	8.9	[2]11.3
Bottom 5 cm	132.7	
Piled	[3]447.3	63.4

[1]N gains based on a chip volume of 360 cubic meters per hectare.
[2]N gain an average of top and bottom chip N-fixation values.
[3]Samples taken from a 46-cm depth in the chip pile.

Table 11.—Lignin and total carbohydrate levels of woodchips at different depths in the chip layer[1]

Depth in chip layer	Lignin[2]	Total carbohydrate
Centimeters	*Percent*	
0- 2	$27.9^{a}(\pm 0.8)$	$65.1^{x}(\pm 1.6)$
10-12	$30.2^{b}(\pm 2.1)$	$63.1^{y}(\pm 2.5)$
[3]24-26	$32.2^{c}(\pm 2.1)$	$59.5^{z}(\pm 3.1)$

[1]Lignin and carbohydrate concentrations were determined using the methods of Moore and Johnson (1967).
[2]Values not showing a letter in common are significantly different, $\alpha = 0.05$; $n = 25$.
[3]Directly above the soil surface.

Table 12.—Average number of active ectomycorrhizae in 50 soil cores (10 by 30 cm) taken from the uncut control stand[1]

Soil strata	Average horizon thickness	Mycorrhizae/ core	Mycorrhizae/cm of horizon
	Centimeters		
Litter (O_1)	0.6	0.6	1.0
Humus (O_2)	.9	11.2	11.9
Decayed soil wood (O_3)	.2	2.0	8.2
Mineral soil, 0-5 cm	5.0	44.2	8.8
5 cm to core bottom	23.7	8.9	.4

[1]Sampled in the first week of July 1978.

Such soil parameters are affected by timber removal and post-harvest site treatments, which could influence the development of ectomycorrhizae on subsequent regeneration (Harvey, Jurgensen, and Larsen 1980). Consequently, basic information was needed on the distribution and activity of ectomycorrhizae in this lodgepole pine ecosystem.

The strong effect of organic matter in promoting ectomycorrhizae development found in other timber types (Harvey, Larsen, and Jurgensen 1980) was not as evident in this stand (table 12). Expressed either as actual root counts or as a percentage (fig. 11), ectomycorrhizal tips were most numerous in the mineral soil. A more favorable ectomycorrhizal response to organic matter is seen where root tip counts are compared on the basis of uniform horizon thickness (mycorrhizae/centimeter of soil layer). Even here, however, the surface mineral horizon is as good a substrate for ectomycorrhizae development as the organic layers. The high activity of ectomycorrhizae in mineral soil is likely due to the relatively moist climate and, probably of greater importance, to the low level of soil organic components. This is best seen in the very low amounts of decayed soil wood in the soil and is related to the frequent fire history in this timber type. Whether the addition of organic matter to the soil as woodchips would affect mycorrhizal development remains to be seen.

LONG-TERM IMPLICATIONS

The timber harvesting and subsequent residue-removal treatments imposed on this lodgepole pine site had significant impacts on soil biological properties. Most affected were the soil organisms involved in soil nitrogen transformations. Increased nitrification in the years following treatment, particularly after a

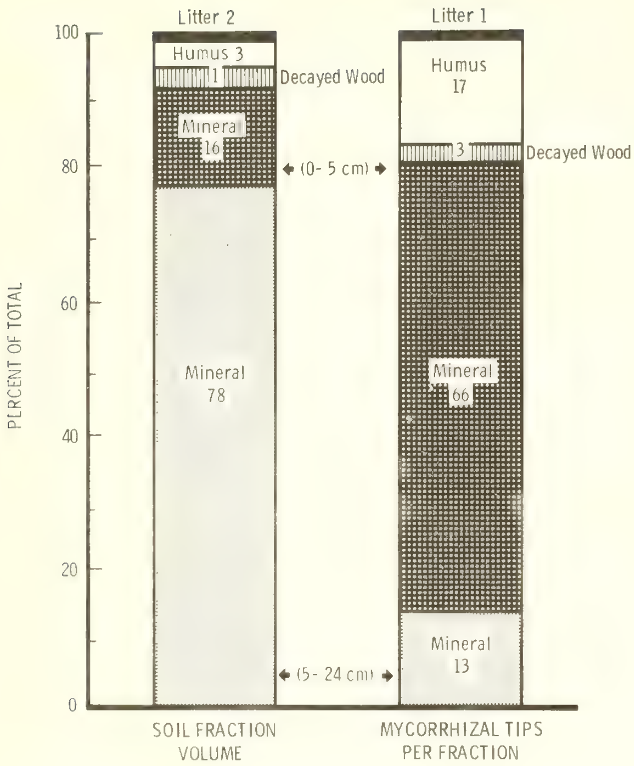


Figure 11.—Relationship of soil fraction to ectomycorrhizal occurrence.

postharvest burn, could enhance nitrogen uptake by subsequent regeneration. Increased nitrogen leached from the site also resulted from increased nitrogen availability. Whether this nitrogen loss, coupled with the nitrogen lost in timber and residue removal, would affect continued stand productivity will depend on the nitrogen status of the soil and the amounts of nitrogen added to the site through rainfall and nitrogen fixation. Such inputs of nitrogen from nonsymbiotic nitrogen fixation were reduced as a result of most site treatments. The fixation rate was so low in the uncut forest soil, the decrease in harvest units may not be significant. The only exception was when the residue was chipped and spread on the site. In this case appreciable amounts of nitrogen were fixed, but the advantage of such a residue conversion is unclear because no comparison can be made to nitrogen gained if the residue was left intact on the site. Of greater importance to soil nitrogen levels may be the establishment of nitrogen-fixing plants, such as lupines, in the stand following harvest. The chip-spread treatment would probably have been more effective in adding nitrogen if small, discrete piles had been scattered over the site (Blanchette and Shaw 1978). This intervening mineral soil also would provide for warming and to serve as a seedbed for regeneration.

In contrast to the biological nitrogen transformations, soil microbial populations and biochemical activities were little affected by the treatments applied. This may be due to a lack of sensitivity in the methods used or to inadequate sampling. The predominance of mycorrhizae in the surface mineral soil of the uncut stand would indicate that soil organic levels may not be as important to mycorrhizae development in lodgepole pine as in other timber types. Nevertheless, this does not mean that stand productivity on these sites cannot be improved by increasing the soil organic component through appropriate residue treatments or fire control. The soil organic component that was present frequently supported high activity. As compared to other Northern Rocky Mountain ecosystems we have studied, this site can be considered low in soil organic matter, particularly decayed soil wood.

As a result, we would generally recommend upgrading the organic matter resource on sites like these by leaving modest volumes of woody residue scattered over the soil surface and by using site preparation measures that minimize loss of soil organic materials.

SECOND RESPONSES

The response of trees, understory vegetation, and wildlife to different treatments is summarized and projected in this section. The analyses are based primarily on observations during the first 5 years after treatment (with some up to 9 years) and projections of those observations. Longer term analyses are discussed in the next section on use opportunities.

Regeneration and Growth of Conifers

Wyman C. Schmidt

In the seeded and planted areas, a sample of 7 to 10 percent of the population was randomly selected for measurement of survival and height development. Trees were measured in the fall of 1973, summer and fall of 1974, fall of 1975, fall of 1977, and planted trees again in the summer of 1981.

To evaluate natural regeneration, 16- to 20-milacre plots were randomly located in each unit. Seedlings were counted to give an estimate of seedling distribution (percent milacre stocking) and seedling density. In addition, cover classes of forbs, grasses and sedges, shrubs, and dead material were estimated in 1975. In 1977, biomass was measured for each of the above categories of vegetation.

PLANTING

Planted seedlings survived very well on the areas that had been dozer-piled and burned (scarified), and those broadcast burned, exceeding 95 percent at 3 years, 87 percent at 5 years, and 80 percent at 9 years (fig. 12). Meanwhile, their counterparts in the residue-removed and chip-spread treatments fared poorly. Although the planted seedlings in the residue-removed treatment were surviving at the rate of over 90 percent at 3 years, they declined rapidly to 59 percent at 5 years and 52 percent at 9 years. Planted seedlings in the chip-spread treatment declined in a similar fashion, dropping from 84 percent survival at 3 years to 49 percent at 5 years, and to 44 percent at 9 years. The survival curves for the last 4 years are essentially parallel for all treatments—the first 5 years accounted for most of the treatment effects.

Pocket gophers and other small mammals were responsible for at least one-third of the seedling mortality on all treatments during the 5- to 9-year age period. Small mammals probably accounted for an even higher proportion, but because of the time lag between measurements not all mortality could be positively identified.

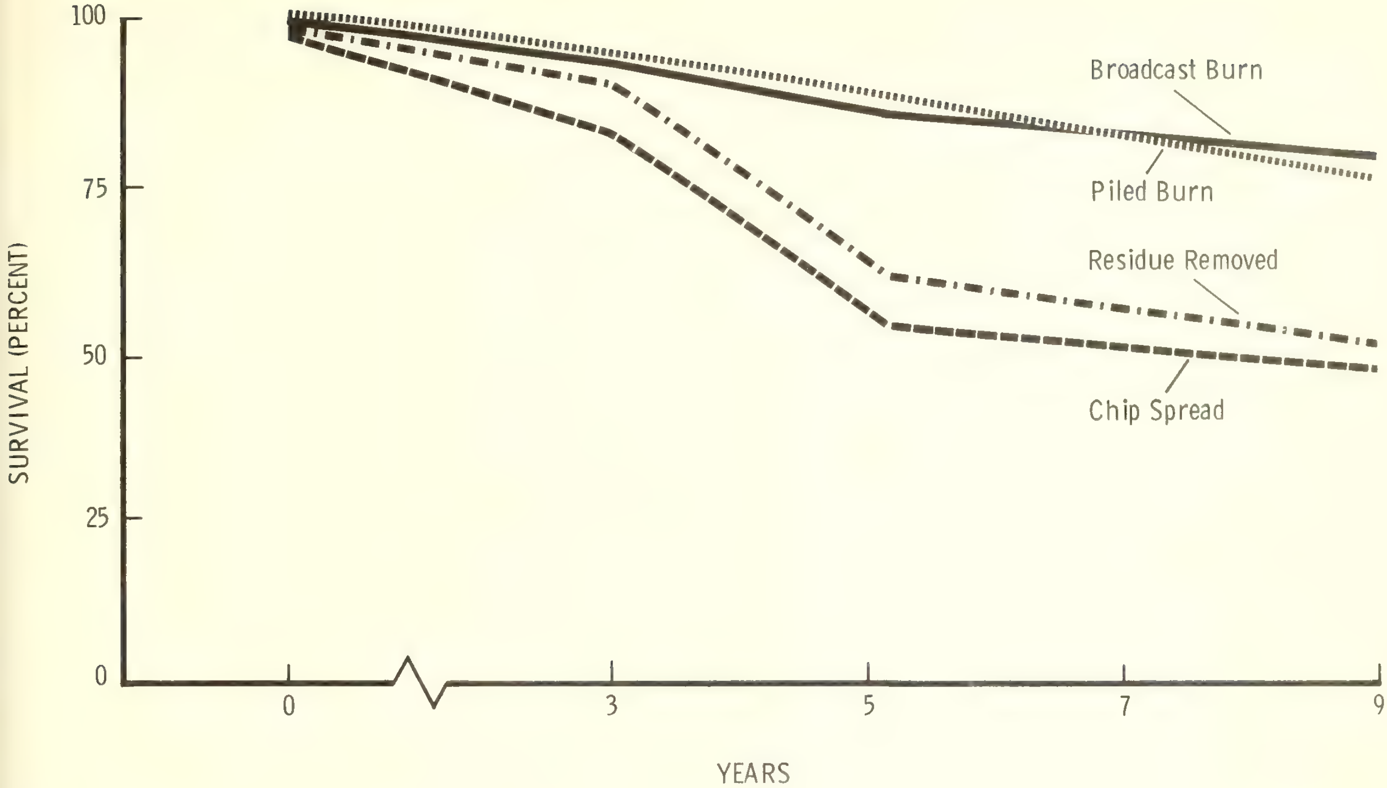


Figure 12.—Survival of auger-planted 2-0 lodgepole pine seedlings under different residues-management methods.

As shown in the following tabulation, declines in survival from age 3 to 5 were partially forecast by the percentage of seedlings with poor vigor at 3 years:

Treatment	Percent of poor vigor trees at age 3	Percent mortality between ages 3 and 5
Pile/burn (scarified)	11	8
Broadcast burn	10	8
Residue-removed	46	22
Chip-spread	40	35

Most of the trees rated poor vigor at age 3 had died by age 5. Although this was a subjective vigor rating based on overall seedling appearance, it forecast the survival rather well for the next 2 years. Comparable vigor ratings were not made at age 5.

In addition to surviving at different rates, planted seedlings grew most on the pile/burn (scarify) and broadcast-burn areas and least on the residue-removed and chip-spread areas (fig. 13). As shown, differences in height were already apparent at age 3, more pronounced at age 5, but beginning to show some amelioration of treatment differences by age 9.

Annual height growth from age 5 to 9 about doubled that noted in the 3- to 5-year period on all treatments, as shown in the following tabulation:

Treatment	Annual height increment Age 3-5 *cm*	*Inch*	Age 5-9 *cm*	*Inch*
Pile/burn (scarified)	8	3	12	5
Broadcast burn	7	3	11	4
Residue-removed	3	1	8	3
Chip-spread	5	2	11	4

Even though height growth differences on three of the treatments appeared to be ameliorating by age 9, growth on the residues-removed treatment was still lagging substantially behind the other treatments.

DeByle (1980) found the weights of typical planted lodgepole pine to vary by treatment (fig. 14). Five years after planting, the chip-spread treatment had the smallest trees (16 g), and the pile/burn (scarify) treatment yielded the largest (49 g). In comparison, seedlings from the spot-seeded sites were much smaller, ranging from approximately 2 g on the chip-spread treatment to 18 g on the pile/burn treatment 5 years after seeding.

The percentage of ash and most nutrients in the planted lodgepole pine were not statistically different among treatments (DeByle 1980). Iron is an exception. New needles of pine planted on the residue-removed units had a much lower iron concentration than did new needles on seedlings from the other three treatments. In contrast, the iron content of roots from residue-removed units was more than twice that found in roots from the other treatments. Based upon both a literature review and field observation, there were no apparent nutrient deficiencies in either the seeded or planted lodgepole pine on

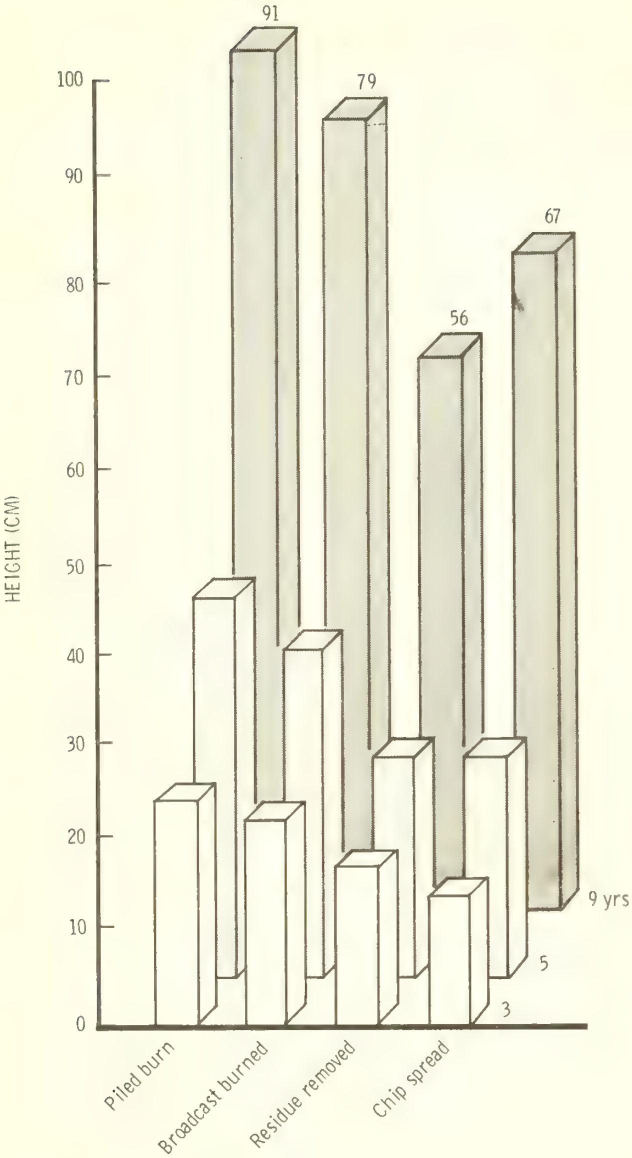


Figure 13.—Height development of auger-planted 2-0 lodgepole pine seedlings under different residues-management methods.

these sites. The markedly different growth rates of trees growing on the four treatments appear to be caused by something other than nutrient availability (DeByle 1980). Possible explanations are examined in a later section, "Factors Affecting Regeneration."

SPOT SEEDING

Broadcast burning and scarification accomplished by piling the slash created conditions most favorable for the establishment of lodgepole pine by spot seeding (fig. 15). Stocking rates for spot seeding on the broadcast-burn and pile-burn treatments were about double those of the residue-removed and chip-spread treatments. Even at that, none of the treatments resulted in stocking rates that exceeded 50 percent 5 years after seeding.

Percentage of stocked plots declined during the period 1 to 5 years in all of the treatments, but stocking on the broadcast-burn and pile/burn treatments appeared to be leveling off. Meanwhile, those in the residue-removed treatment continued a steady decline throughout the 5-year period, and those in the chip-spread dropped substantially between years 1 and 3, but declined at a slower rate in years 3 to 5 than previously.

Residue treatments influenced the first 5 years' height growth of the spot-seeded seedlings in much the same manner as they did the stocking rates. Height growth was twice as great on the broadcast-burn and pile/burn areas as on the residue-removed and chip-spread treatments, based on the tallest seedling in each seed spot (fig. 16). These differences were already significant at 3 years and even more pronounced at 5 years.

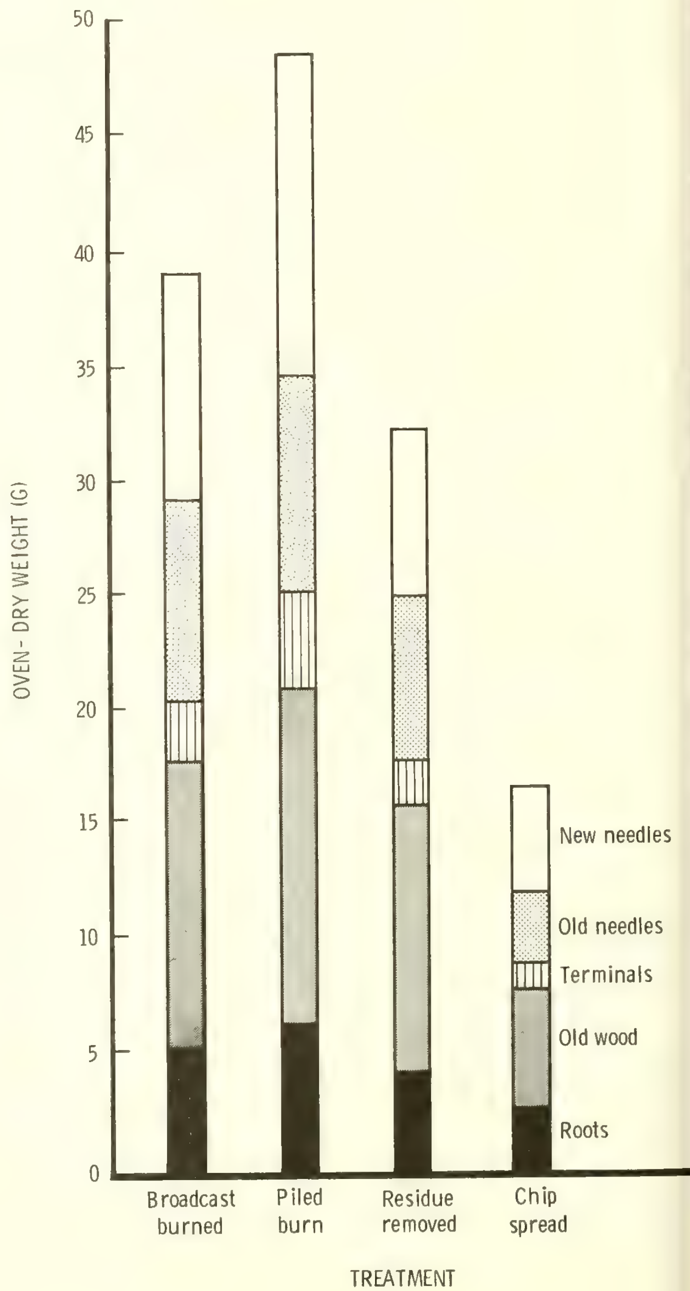


Figure 14.—Weights, by component, of typical lodgepole pine 5 years after planting on each treatment.

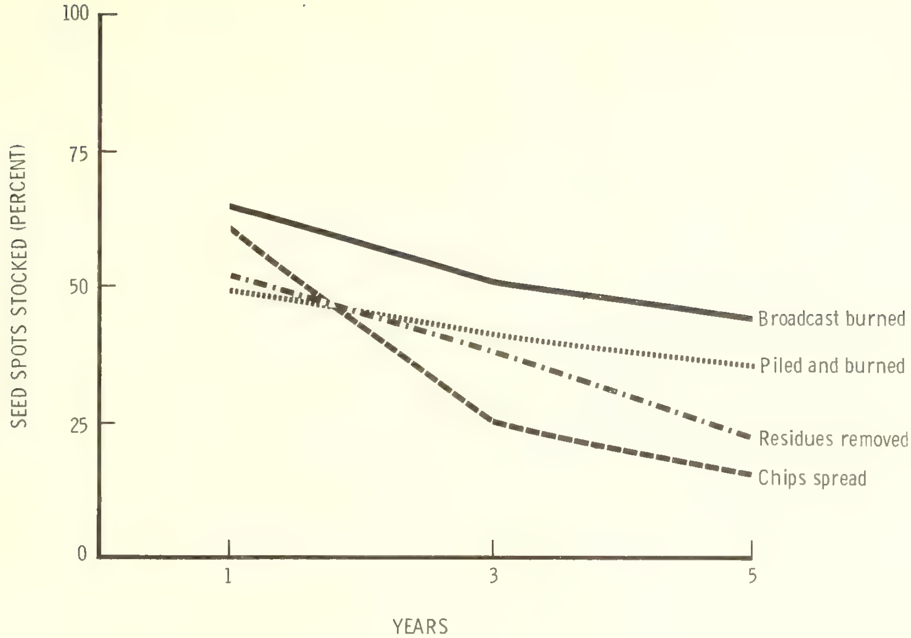


Figure 15.—Percent of seed spots stocked with lodgepole pine seedlings under different residues-management methods.

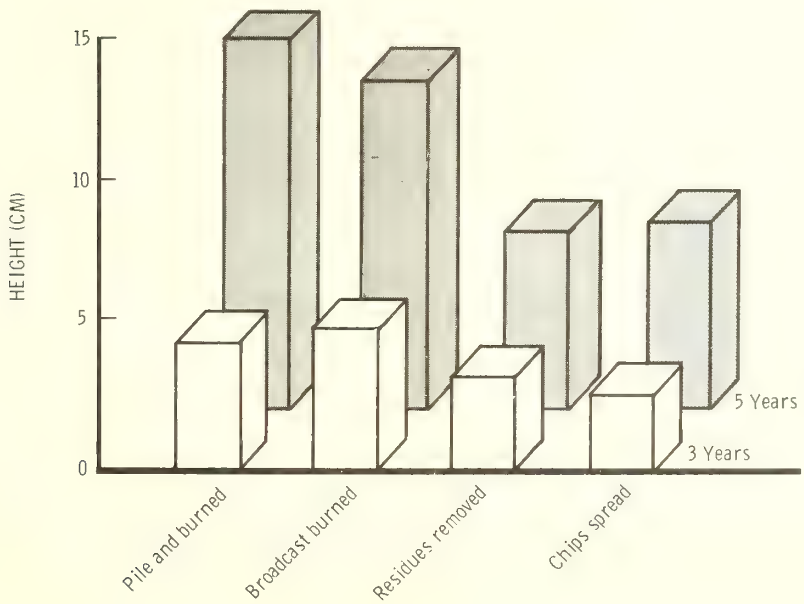


Figure 16—Average height of the tallest seedling per seed spot by residues treatment and year.

Table 13.—Natural regeneration of lodgepole pine at 3 and 5 years under different residues management methods

Treatment	Years after treatment	Milacre stocking	Seedling density		Height of dominant seedlings 5 years after treatment	
		Percent	*Per acre*	*Per ha*	*Inches*	*cm*
Pile/burn (scarified)	3	56	2,220	5 483	—	—
	5	66	2,630	6 496	7.5	19.0
Broadcast burn	3	11	130	321	—	—
	5	20	300	741	2.0	5.1
Residue-removed	3	50	1,890	4 668	—	—
	5	35	1,200	2 964	5.0	12.7
Chip-spread	3	3	30	74	—	—
	5	9	230	568	1.6	4.1

NATURAL REGENERATION

Natural regeneration was more than adequate on the pile/burn treatment, averaging about 2,630 trees per acre (6 500 per hectare), with a 66 percent stocking rate (table 13). At age 5, the area was stocked with nearly 1,200 trees per acre (3 000 per hectare), with a 35 percent milacre stocking rate. However, both stocking rate and seedling density were less than adequate on two other treatments. A good estimate for the broadcast-burn treatment is not possible because a good seed fall occurred in 1971 immediately following logging, but before burning in the spring of 1973. Nearly all of the seedlings that germinated in 1972 were probably consumed in the fire. Poor seed production in subsequent years left the broadcast burn with few seedlings, even after 5 years.

Very little natural regeneration was evident at 3 years on the broadcast-burn and chip-spread treatments, and even by age 5 only a few poorly distributed seedlings were established (table 13). This poor showing, however, was attributed to having burned up the 1972 seedlings rather than due to the treatment per se. Natural regeneration was fairly successful on the residue-removed treatment at age 3, but both stocking rate and seedling density declined in the following 2 years.

Average seedling heights were closely related to the number and stocking of seedlings established on the different treatments—those with the greatest stocking also produced the tallest average trees. Some of the differences in height were likely a function of seedling age. For example, nearly all of the seedlings now found in the broadcast burn were established about 3 years after those in the pile/burn treatment.

FACTORS AFFECTING REGENERATION

The survival and growth data above indicate that the method used to dispose of wood residues following clearcutting in lodgepole pine forests clearly affects subsequent regeneration. This holds true for both survival and initial development of both artificial and natural lodgepole pine regeneration. Differential effects of the residue treatments are pronounced after 5 years and measurements at 9 years of the planted seedlings indicate treatment differences still persist. The general trend hints that some of the differences will continue—how long can only be speculated at this time. Studies with western larch (*Larix occidentalis*) under somewhat similar circumstances showed seedbed treatments affecting seedling and sapling development for 15 to 20 years (Schmidt 1969; Schmidt and others 1976).

The more conventional methods of seedbed preparation in lodgepole pine forests resulted in the best survival and seedling development in this study. Both dozer piling and burning, and broadcast burning are used extensively in lodgepole pine forests for seedbed preparation. Results from this study provide additional support for those methods as far as seedling establishment and development are concerned. This held true for all three types of regeneration practices—planting, spot seeding, and natural.

For the first 5 years, the residue-removed and chip-spread treatments had poor regeneration, and their long-term trend is not favorable. For example, planted tree survival and growth on these treatments is substantially less than on the two conventional treatments, and the trends are persistent. The same relationship holds true for spot seeding, and, to a lesser extent, for natural regeneration. The natural regeneration picture for the broadcast burning is clouded because of the delayed burning and subsequent loss of first-year seedlings. Other studies have indicated that natural regeneration on pile/burn and broadcast-burn areas is essentially the same, but with somewhat fewer seedlings surviving in the burned seedbeds (Alexander 1966).

Many individual factors or combinations thereof probably contribute to differences in seedling response. One possibility is the difference in soil temperatures reported in the previous section. Soil temperatures under the chip-spread treatment ranged from 5° to 20° cooler than some of those in the open (Hungerford 1980). As described by Lotan and Perry (1976), cool soil temperatures can inhibit plant-water uptake, retard nutrient release and absorption, and slow terminal leader growth of plants, perhaps by inhibiting hormone transfers from root to top. Differences in net radiation could also be involved, but at this time the implications of net radiation are not fully understood.

Nutrients are often felt to be a major cause of differential tree response on areas treated with some of the residue disposal methods used in this study. Broadcast burning increased levels of potassium, calcium, magnesium, and nitrates (DeByle 1980) and may have contributed to the superior growth of the regeneration that developed as a result of seeding. But planted seedlings did not similarly respond—probably because the flush of available nutrients essentially disappeared the second season, before the

seedlings developed a root system capable of capitalizing on the nutrients.

Concentrations of nutrients in the planted seedlings growing on the different seedbeds gave no ready explanation for growth differences. As indicated previously, major nutrients were similar in the different lodgepole pine seedling components in the different treatments. However, the evaluation of true nutrient availability and disposition is difficult because on more favorable treatments seedlings grew larger, and nutrients therefore may appear to be less concentrated.

Interestingly, the two treatments with the least tree response also were the treatments with the greatest percentage of organic matter in the upper 2 in (5 cm). Much of the nitrogen in this strata may have been "tied up" in the decomposition process and as a result unavailable to the seedlings even though present. Compaction did not appear to adversely affect initial establishment and development here. Data reported earlier indicate the most compaction (as measured by bulk density) occurred on the scarified areas—the areas that produced the best seedling response.

A flush of phenols in 1973, the first year seedlings were planted and seeded, may have played an active role in retarding seedling establishment and subsequent growth. If so, the high contents of phenols—658 parts per billion in the chip-spread and 320 parts per billion in the residue-removed treatments—had a long-term compounding effect because phenol levels had returned to normal by 1974 (Hart and DeByle 1975). Plant tissue commonly contains phenols (Bate-Smith 1962) with high concentrations in dead and dying woody plants (Jorgenson 1961; DeGroot 1966). Phenols are credited with both stimulating (Michniewicz and Galoch 1974) and inhibiting (Mensah 1972; Demos and others 1975) plant growth.

Interestingly, high phenol levels on the chip-spread and residue-removed treatments were associated with organic matter levels in the top 2 in (5 cm) of the soil. As described earlier, organic matter accounted for 11 to 12 percent of the upper soil layer in the residue-removed and chip-spread treatments in 1975 as compared to 4 to 6 percent in the other treatments. The increased organic matter in the upper soil of the residue-removed treatment was believed due to the incorporation of fine residues, such as pine needles, into the upper soil during the intense removal of all the larger residues.

Projections of Timber Stand Development

Dennis M. Cole

The previous section covered tree survival and early growth of lodgepole pine regeneration on the different residue treatment areas. These data were the basis for computer projections of stand development with a revised version of "LPMIST" (Myers and others 1972). The projections provide a comparison of treatments at different future ages by such characteristics as expected volume, increment, and tree size. The projection model used is designed to make decadal projections, beginning at age 20, of several key parameters of stand growth and yield—average stand diameter by basal area, mean height of dominant trees, and stocking in trees per acre—as a function of site index, elevation, and initial values of average stand diameter, mean height of dominants, and trees per acre.

Measurement data were only available at 3, 5, and 9 years for planted regeneration, and for only 3 and 5 years for direct-seeded and natural regeneration. Twenty-year values for starting the projections were derived for two assumed stand development scenarios that are plausible alternatives for stand development, from 5 to 20 years following stand regeneration. The first alternative assumes essentially no further seedling mortality from the last measurement to year 20. The second alternative assumes that noncatastrophic mortality under all methods of regeneration will continue during the period 5 to 20 years, at an average rate of 1.5 percent per year. This rate was observed for planted seedlings in the period from 5 to 9 years following planting. Which of the two assumptions is more applicable for each of the regeneration methods—or whether an intermediate rate of mortality between the two assumed is involved—can only be determined by future remeasurements of the study plots. In the interim, however, we believe that by keeping our assumptions clearly in mind, we can tentatively gain some idea of the magnitude of long-term effects of the residue treatments by projecting stand development under these two different, yet plausible, courses of early survival and growth. Unforeseen events such as wildfire, insect or disease epidemics, and additional (excessive) natural regeneration can alter the future stand; however, these factors are not built into our projections.

The 12 residue-treatment/regeneration-method combinations of the study were projected by 10-year growth intervals under each of the above-mentioned assumptions to 150 years. Projected volumes, mean annual increments, and ages at increment culmination are shown for total cubic volumes and board-foot volumes of each treatment (tables 14a and 14b). Also shown is the number, d.b.h., and board feet represented by the average tree at culmination of board-foot increment. Supplemental tables were developed to summarize for each treatment and assumption (at the culmination of board-foot MAI): (1) volume, stocking, and average size of green and dead standing timber; (2) volume of both green and dead residues; and (3) expected timber values (appendix tables 31-35). From the projections and the resultant summary tables, growth curves and average d.b.h.'s were developed for the maximum and minimum values of each stocking assumption to illustrate the respective ranges in which all treatment responses appear to occur (figs. 17 and 18). The principal differences among the stocking assumptions, and among treatments within a stocking assumption, appear to be:

1. *Cubic volume and growth.*—Culmination of mean annual increment occurred at from 70 to 90 years for stocking assumption 1, and from 70 to 100 years for stocking assumption 2, depending on treatment. Total volume under assumption 1 varied from 3,980 ft^3 per acre (278 m^3/ha) (broadcast burn with natural regeneration) to 5,250 ft^3 per acre (367 m^3/ha) (pile/burn with spot seeding). Under assumption 2, total volume varied from 3,270 ft^3 per acre (229 m^3/ha) (chip-spread with spot seeding) to 5,060 ft^3 per acre (354 m^3/ha) (broadcast burn with planting). Differences appear to be related to differences in trees-per-acre stocking among the treatments.

2. *Saw log volume.*—Culmination of mean annual increment on a board foot basis occurred at 90 to 130 years for stocking assumption 1, and at 110 to 130 years for assumption 2. Total volume at culmination was between 18.1 and 23.4 M bd.ft. per acre (44.7 and 57.8 M bd.ft./ha) for both stocking assumptions, except on direct seeding after piling and burning, under assumption 1, where volume was 16.6 M bd.ft per acre (41.0 M bd.ft./ha).

3. *Tree stocking and size.*—There is a notable difference between stocking assumptions and among treatments as to the

Table 14a.—Projected volume, mean annual increment, and tree size, by treatment (assumes no substantial mortality between ages 5 and 20)

Treatment	Total cubic volume all trees to tip			Saw log volume - bd.ft. of trees 6.5 in d.b.h. to 6.0 in top					
	Culmination of cubic foot MAI		Total volume at culmination of MAI	Culmination of bd.ft. MAI		Total volume at culmination of MAI	Average tree at culmination of bd.ft. MAI		
	Age	MAI		Age	MAI		No./acre	Average d.b.h.	Volume of average tree
	Yrs	*Ft³/yr*	*Ft³/acre*	*Yrs*	*Bd.ft./yr*	*M bd.ft./acre*		*Inch*	*Bd.ft.*
Pile and burn (PB)									
Planted (P)	90	56.8	5,110	100	187	18.7	400	9.1	47
Seeded (S)	90	58.4	5,250	90	184	16.6	458	8.5	36
Natural (N)	70	60.8	4,250	130	146	19.0	675	7.4	28
Broadcast burn (BB)									
Planted (P)	90	56.8	5,110	100	187	18.7	400	9.1	47
Seeded (S)	90	56.8	5,110	100	187	18.7	400	9.1	47
Natural (N)	80	49.8	3,980	120	193	23.1	198	12.1	117
Chip-spread (CS)									
Planted (P)	90	51.8	4,060	120	194	23.3	225	11.6	104
Seeded (S)	90	47.7	4,290	110	191	21.0	176	12.4	119
Natural (N)	90	47.6	4,280	120	192	22.9	157	13.1	146
Residue-removed (RR)									
Planted (P)	90	53.3	4,790	120	195	23.4	249	11.2	94
Seeded (S)	90	56.8	5,110	100	187	18.7	400	9.1	47
Natural (N)	80	58.3	4,660	110	165	18.1	532	8.1	34

Source: Projections by D. M. Cole, Intermountain Forest and Range Experiment Station, Bozeman, Mont.

Table 14b.—Projected volume, mean annual increment, and tree size, by treatment (assumes 1.5 percent annual mortality between ages 5 and 20)

Treatment	Total cubic volume all trees to tip			Saw log volume - bd.ft. of trees 6.5 in d.b.h. to 6.0 in top					
	Culmination of cubic foot MAI		Total volume at culmination of MAI	Culmination of bd.ft. MAI		Total volume at culmination of MAI	Average tree at culmination of bd.ft. MAI		
	Age	MAI		Age	MAI		No./acre	Average d.b.h.	Volume of average tree
	Yrs	*Ft³/yr*	*Ft³/acre*	*Yrs*	*Bd.ft./yr*	*M bd.ft./acre*		*Inch*	*Bd.ft.*
Pile and burn (PB)									
Planted (P)	80	55.6	4,440	110	196	21.6	297	10.4	73
Seeded (S)	80	50.7	4,050	120	193	23.2	208	11.9	112
Natural (N)	70	58.8	4,110	130	148	19.3	614	7.7	31
Broadcast burn (BB)									
Planted (P)	90	56.3	5,060	110	196	21.6	313	10.2	69
Seeded (S)	90	53.3	4,950	120	195	23.4	249	11.2	94
Natural (N)	90	48.6	4,370	110	194	21.3	176	12.4	121
Chip-spread (CS)									
Planted (P)	80	49.4	3,950	110	192	21.1	194	12.0	109
Seeded (S)	80	40.9	3,270	110	186	20.5	107	14.6	192
Natural (N)	100	44.8	4,470	110	192	21.1	137	13.5	154
Residue-removed (RR)									
Planted (P)	80	49.8	3,980	120	192	23.1	198	12.1	117
Seeded (S)	100	46.3	4,120	110	195	21.4	151	13.1	142
Natural (N)	80	59.7	4,770	110	170	18.7	505	8.3	37

Source: Projections by D. M. Cole, Intermountain Forest and Range Experiment Station, Bozeman, Mont.

nature of the stands. Under assumption 1, stocking at culmination of board-foot MAI is seen to vary on 7 of the 12 treatments from 675 to 400 trees per acre (1 667 to 988/ha), averaging 7.4 to 9.1 in (18.8 to 23.1 cm) d.b.h. The other five treatments are notably different. On the chip-spread (all regeneration methods), the broadcast burn with natural regeneration, and the residue-removed with planting, stocking varied from about 160 to 250 trees per acre (395 to 617/ha), with diameters averaging from 13.1 to 11.2 in (33.3 to 28.4 cm). In contrast, at culmination of board-foot MAI under assumption 2, only the pile/burn with natural regeneration (614 trees/acre; 1 517/ha), the residue-removed with natural regeneration (505 trees/acre; 1 247/ha), the broadcast burn with planting (313 trees/acre; 773/ha), and the pile/burn with planting (297 trees/acre; 733/ha), exceeded 250 trees per acre (617/ha). The average d.b.h. of these treatments ranged from 7.7 in (19.5 cm) with 614 trees per acre (1 517/ha), to 10.4 in (26.4 cm) with 297 trees per acre (733/ha). The remaining eight treatments under assumption 2 showed stocking levels between 107 and 249 trees per acre (264 to 610/ha), with corresponding diameters in the respective range of 14.6 to 11.2 in (37.1 to 28.4 cm).

In summary, although neither cubic-foot nor board-foot volumes were greatly influenced by the different stocking assumptions, tree sizes and value considerations were considerably affected. Differences in tree size among treatments, within stocking assumptions, were also noted and discussed in the preceding paragraph. Additional insight on these effects can be gained by examining supplementary tables 31–35 of the appendix, where ramifications of tree size and value are expressed in additional ways that are important for assessing tradeoffs in resource values.

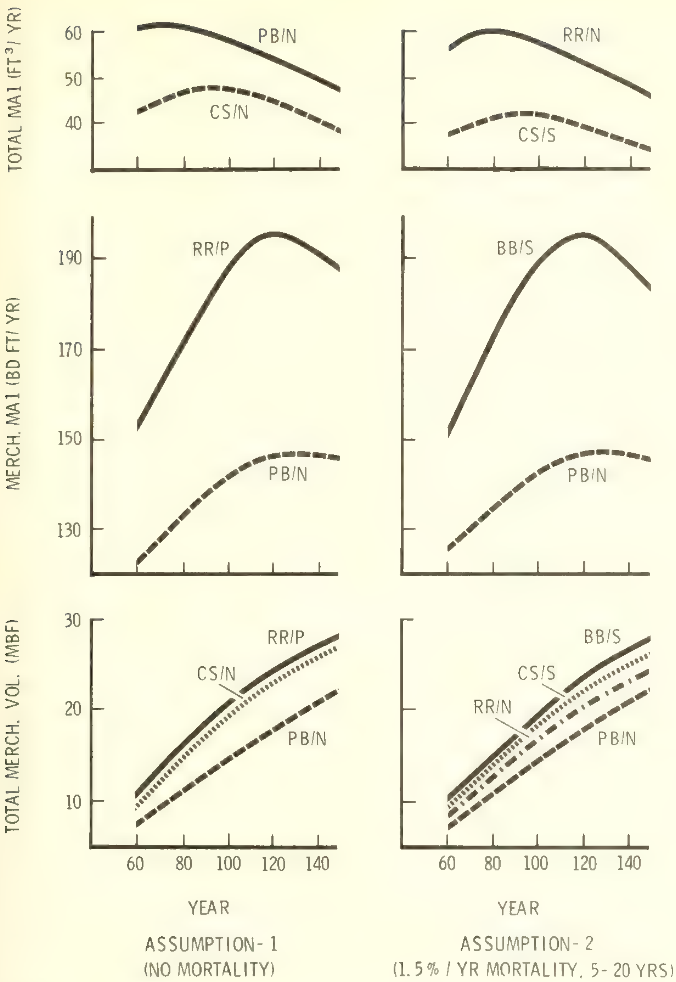


Figure 17.—Growth and volume projection—selected treatments.

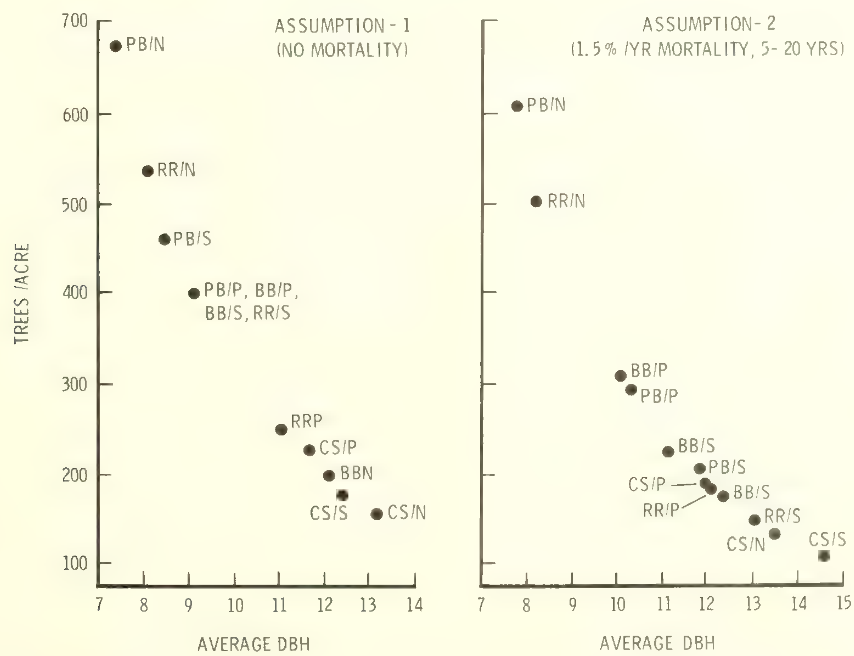


Figure 18.—Average d.b.h. and stocking of dominant and codominant trees at culmination of board foot mean annual increment.

Regrowth of Understory Vegetation

Wyman C. Schmidt

Vegetative cover was measured 3 years after treatment and averaged 11 percent forbs and 2 percent grasses and sedges on the scarified and broadcast-burn treatments; and 20 percent forbs and 9 percent grasses and sedges on the residue-removed treatment. There was practically no vegetative cover on the chip-spread treatment.

The biomass of vegetative components varied substantially. As shown in figure 19, understory vegetation was sparse in the uncut mature forests in the study area. With the exception of the chip-spread treatment, all of the treatments produced more vegetation than the uncut forest. Forbs accounted for about a third of the understory biomass in the uncut forest, but they predominated on the treated areas. For example, in the burned-treatment area, forbs accounted for over three-fourths of the biomass. On the other hand, shrubs accounted for a third of the biomass in the uncut forest and were practically nonexistent on the treated areas. Grasses were practically nonexistent in the uncut forest and the chip-spread treatment, but accounted for over a third of the biomass in the pile/burn and residue-removed treatments.

Vegetative competition commonly inhibits seedling survival and development. With the possible exception of the residue-removed treatment, however, vegetative competition does not appear to be significant in this case. The relatively low levels of vegetation measured as live biomass on the entire area casts doubt on its role as a strong competitor. The grass component would likely be the primary competitor, but the amounts of grass on the pile/burn treatment (which produced the best tree growth) was essentially the same as on the residue-removed treatment (which had poor tree growth).

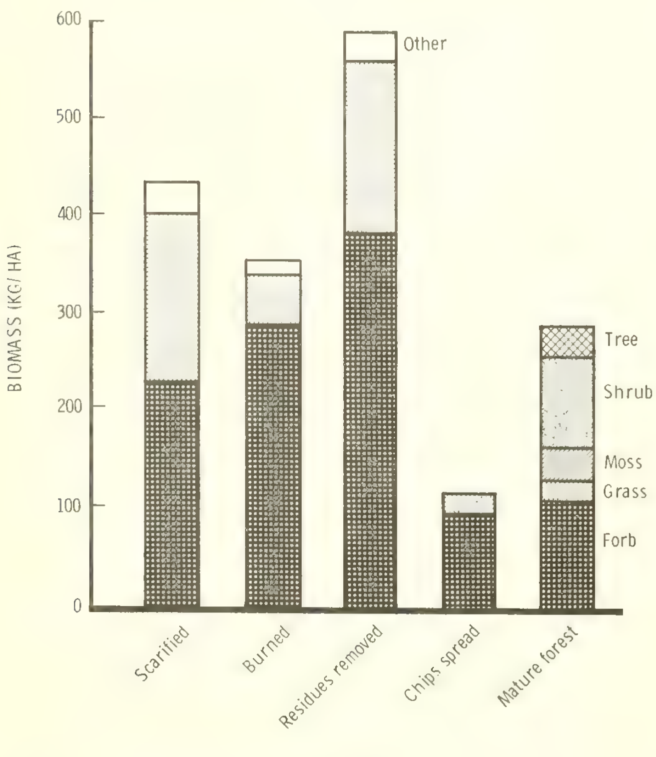


Figure 19.—Biomass of the understory vegetation 5 years after clearcutting and subsequent residues treatments.

Understory vegetation was sampled prior to harvesting and also in connection with the infiltrometer plots. The total biomass varied slightly from that in figure 19, probably because of sampling differences and also seasonal and year-to-year differences. Nevertheless, the relative differences among treatments were about the same.

To fully assess potential effects of future treatments, growth of understory vegetation was projected to complement the tree growth projections. Past research indicates that understory vegetation typically peaks at about 12 years after harvest, and produces about 800 to 900 lb per acre (900 to 1 000 kg/ha) at the peak (Basile 1971). Projections of the data indicate the chip-spread treatment will remain low, under 100 lb per acre (110 kg/ha), but the other treatments will produce about 950 to 1,200 lb per acre (1 050 to 1 350 kg/ha) at 12 to 13 years (fig. 20). Beyond that time, as tree crowns begin to shade the understory vegetation, herbage production on most treatments will tend to equalize at about the level of the uncut forest by year 25. Vegetation will probably remain sparse on the chip-spread treatment. This is speculation because we know of no previous experience with spreading chips on forest sites.

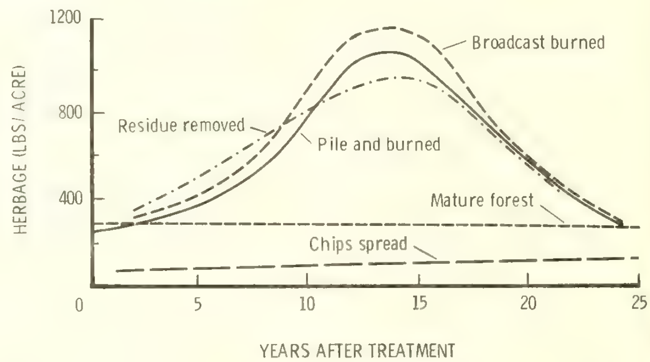


Figure 20.—Projected production of understory vegetation.

Wildlife

Joseph Basile

The scope and design of this study allowed for only limited direct evaluation in terms of wildlife. For the most part studies evaluate the effect of treatments on wildlife habitat. This section reports on the immediate effects of treatment.

EFFECTS ON WILDLIFE HABITAT

The evaluation of treatment effect on wildlife and domestic livestock is based partly on vegetation and regeneration data, but mostly on intuitive expectations derived from professional experiences of several individuals. What follows, then, is largely opinion; but, we feel, an informed opinion.

Although expectations are discussed here for the treated sites, it is unrealistic to view their effects on wildlife as entities in themselves. Except for a few species of small mammals, none of the wildlife species rely solely on habitat contained wholly within the treated site. Rather, the individual ranges of most mammals and birds will encompass parts or all of several units within the area. Most species will fare best where those units present a variety of stages of vegetation development and complexity. The "edges" between uncut forest and cut blocks, and between cut

blocks of widely differing ages, are especially important, particularly to some of the larger animals that require a taller protective screening than that provided by early seral stages.

All treatments, except the chip-spread, produced within 5 years understory vegetation superior to that of the uncut forest both in amount and in species diversity. Cover, however, which is also essential to most wildlife species, is in part tied to residues left on the site and conifer regeneration and growth, as discussed in the following treatment assessments made about 5 years after harvest.

Chip-spread.—This treatment is undesirable for wildlife. Herbaceous vegetation is expected to be unacceptably low, both in species diversity and in total production, for two or more decades. Natural regeneration of lodgepole pine is highly unlikely. The performance of direct-seeded and planted stock 5 years after planting indicates poor survival and growth rates. Thus, both food and cover for small and large mammals and for birds are expected to be lacking for at least 20 years, and possibly much more.

Residue-removed.—This treatment is the least disruptive to the soil and thc understory vegetation. Consequently, more biomass is expected here than on other treatments for the first few years after logging. With the relative absence of scarification and with no burning, however (both of which promote herbage production), less biomass is expected here for about two decades than on the broadcast or pile/burn treatments. Relatively poor performance of tree regeneration, coupled with the absence of logging debris, renders the residue-removed treatment units devoid of significant hiding cover for most mammals and of perching opportunity for birds. As herbaceous vegetation cover increases, the area should become more attractive to small rodents and, in turn, to raptors.

The removal of all snags, limbs, and other logging debris eliminates the impediment to livestock and big-game travel often imposed by debris on conventionally logged areas.

The net long-term effect of this treatment is beneficial to wildlife and to livestock. Herbaceous production should equal or exceed that of the uncut forest within 3 or 4 years after logging, and should continue to increase until peaking at about 15 to 20 years. Cover should be adequate for most small mammals within 5 years, and for larger mammals (deer, elk) in 20 to 25 years.

Broadcast burn.—This treatment is perhaps the most beneficial to wildlife, in that it combines a high forage production with good escape cover within a relatively short time. Survival and growth rates of lodgepole pine 5 years after planting were higher than on the residue-removed units, giving rise to expectations of a somewhat faster attainment of good cover conditions for large mammals here than on the complete removal units. Production of herbaceous vegetation will exceed that of the uncut forest in 3 to 5 years, and should peak in 10 to 15 years at a level above that of the residue-removed areas.

Unburned logging debris is usually sufficient to provide immediate cover for small mammals and roosts for passerine birds. At the same time, the debris is not concentrated enough to seriously impede travel by big game or livestock. The suitability of the habitat for small mammals enhances its attractiveness for raptors and carnivores.

Pile/burn.—This treatment will generally yield less herbaceous vegetation, and at a slower rate than the broadcast-burn treatment. This is partly because soil is displaced in piling, and partly because soil is temporarily sterilized by extremely hot, prolonged fire in concentrated slash piles. Nonetheless, the biomass should peak in approximately 15 years at a level above that of the residue-removed unit.

Cover for small rodents and perches for songbirds are generally abundant, and so in turn it is favorable to raptors and carnivores. Unburned log piles are conducive to good marmot habitat. Unburned debris on pile/burn sites, however, particularly when the slash is windrowed, may hinder elk travel and discourage use.

Stocking, survival, and growth rates of planted lodgepole pine can be expected to be very good on pile/burn sites. The screening effect of young trees, coupled with that of the slash piles, combine to rather rapidly provide a protective cover for the larger mammals as well as the rodents.

To summarize the four treatments, then, we may expect herbaceous vegetation to respond similarly to all but the chip-spread treatment; that is, a rapid rise in production, peaking at about 10 to 15 years at not widely divergent levels.

The protective cover afforded wildlife differs more with treatment than does herbage production. Ample cover and perches provided by logging debris remaining after broadcast or pile/burn treatments render these areas immediately more suitable for small mammals and birds, and thus to carnivores and raptors, than are areas from which all residues are removed. These differences in cover values are further magnified by the higher survival and growth rates of lodgepole pine stock on the conventionally treated areas.

OBSERVATIONS OF WILDLIFE

The following wildlife were observed one year after the harvest:

Old-growth, uncut.—Juncos, chickadees, nutcrackers, and various woodpeckers were common. Red squirrels and chipmunks were common; few pocket gophers.

Older clearcuts in area.—Twenty-three species of birds, including open meadow species. Droppings from hare, porcupine, bear, coyote, moose, elk, and deer.

Study units, first year.—Birds limited to edge of cutting units. Pocket gophers emigrated about 1 chain into unit during the first winter but population was low.

In subsequent years, researchers at the site have made casual observations of wildlife. Elk and moose use the areas each year even though it has been fenced to exclude livestock. Moose have destroyed portions of the fences. Small birds are seen in the areas, although more so in the burned units where logs provide perches. There does not appear to be as many varieties or numbers of birds in the study units as in older clearcut units. In general, wildlife response appears to be as expected by wildlife biologists when they initially viewed the treatments.

Rodents are of particular concern in areas to be regenerated because they eat seeds and gnaw on roots or stems of seedlings. As noted earlier, rodent poison was distributed the year the area was regenerated. No population estimates were made prior to

harvest, but in subsequent years some snap trapping was done in the area.[3] This was not a rigorously designed study and it is not possible to derive estimates of rodent population density from the data. The following tabulation indicates that the population may be much reduced where residues were removed. Unfortunately no data were taken in the chip-spread treatment.

Treatment	Percent of trap sets[1] that were "hits" (animal caught or trap sprung)
Uncut timber	30
Broadcast burn	26
Pile/burn	21
Residue-removed	16

[1]Using χ^2 test, hit rate in uncut timber and broadcast burn is significantly different from hit rate in pile/burn and residue-removed (at the 0.95 level of probability).

These trapping data tend to substantiate predictions of wildlife habitat for different treatments. Little evidence has been noted of rodents in the chip-spread treatment.

The evaluations of treatment effects on wildlife are based primarily on the differences in herbaceous cover. The importance of these cover differences diminishes with time and with proximity to edges of older cuts and uncut forest. Thus, effects of treatments on wildlife are best understood when the working circle, with its mosaic of cuts of various ages, sizes, and shapes, is viewed in its entirety. For comparative purposes, however, the changes in forage and cover are used directly as indicators of differences in the effect of treatments on wildlife, and are analyzed further in the next section on use opportunities.

EFFECTS ON USE OPPORTUNITIES

The preceding sections have described the physical and biological responses to various harvesting and regeneration treatments. For this information to be useful for management, it was necessary to project the future development of trees and lesser vegetation and interpret the responses in terms of the resources the manager works with. To translate observations made on these specific harvesting sites into a broader analysis, it was necessary to make two additional assumptions:

Spatial aspects.—Our assessment is primarily tied to the harvest unit. Most of the wildlife and some of the vegetation responses are not limited to the onsite harvest unit effects. The arrangement and extent of cutting units and related spatial aspects such as proximity to streams and roads are beyond the scope of this analysis. For example, the effect of one cutting unit in isolation will be different than the effect of 10 units in close proximity along a road. We do not address these aspects here.

Measures of response and use opportunities.—Ideally all impacts and responses would be measured by a common scale such as dollars. Nevertheless, not all responses can be interpreted in common units. Therefore, several measures are used: dollars, quantities, or in some cases, a simple index of favorable or unfavorable responses.

[3]James E. Lotan. Data on file at FSL, Missoula, Mont. 1973.

The following sections compare and analyze the impact of treatments on several principal use values: wildlife, grazing, recreation and esthetics, soil and water, and timber.

Wildlife Values

The discussion of wildlife impacts in the preceding section focused on habitat changes plus limited data on species and population trends. The combination of early habitat effects, projections of vegetation response, and wildlife observations provides a reasonable basis for estimating wildlife responses.

In 1972 the Teton National Forest wildlife biologist evaluated the areas in terms of effects on wildlife.[4] Field sampling and observations of both wildlife and vegetation were combined into an index value for three time periods (at harvest, 20 years hence, and 100 years hence). Ratings developed for elk and birds shown in figure 21 are typical. Additional analyses for other species are summarized in the appendix.

Both burning treatments and residue-removed treatments were projected to be virtually the same in terms of forage and cover. Unharvested stands are superior to harvesting treatments in terms of cover, but over time forage is projected to increase on harvested areas and decrease on unharvested stands. Habitat for birds in piling and burning areas was superior to residue-removed areas in providing perching places and in the amount of food produced.

Although these evaluations were of necessity largely subjective, both burning and residue-removed treatments were judged to offer little immediate forage and cover for big game. The chip-spread areas were judged to offer even less in vegetation response and wildlife potential.

Interpreting these responses in terms of resource uses involves some assumptions as to what is "good" and what is "bad." For example, what is good for one wildlife species, such as pocket gophers, may be bad for timber because gophers damage roots of young trees.

The general context in which wildlife is evaluated must then be established. For each of the species or groups of species evaluated, the following assumptions were used:

Moose, elk, and deer.—Although these animals may do some damage to tree regeneration and may compete with cattle for herbage, in our assessments they are assumed to have positive value. They are commonly seen feeding in harvest units in the area, but the importance of cutting units to total food intake has not been established. Elk apparently use the study area only as transitional range enroute from lower elevation winter habitat to higher elevation summer range. Deer are not numerous in the area but seem to use the cutting units throughout the summer.

Differences among treatments in the production of herbaceous material could potentially affect big-game foraging. Because this is a transitional range and only lightly used, only a small part of what is produced is actually used. Casual observation over several years indicates that elk sedge was the primary forage, and this was utilized mostly early in the season. Small alpine fir has been closely browsed by moose, and forbs are utilized by all big game. For this reason the herbage production reported above could indicate differences between treatments in browse potential for big-game animals, but from a practical standpoint these differences will probably have little actual effect on use by elk, deer, or moose.

[4]Office report by George Gruell, June 15, 1973, on file at Intermountain Forest and Range Experiment Station, Missoula, Mont.

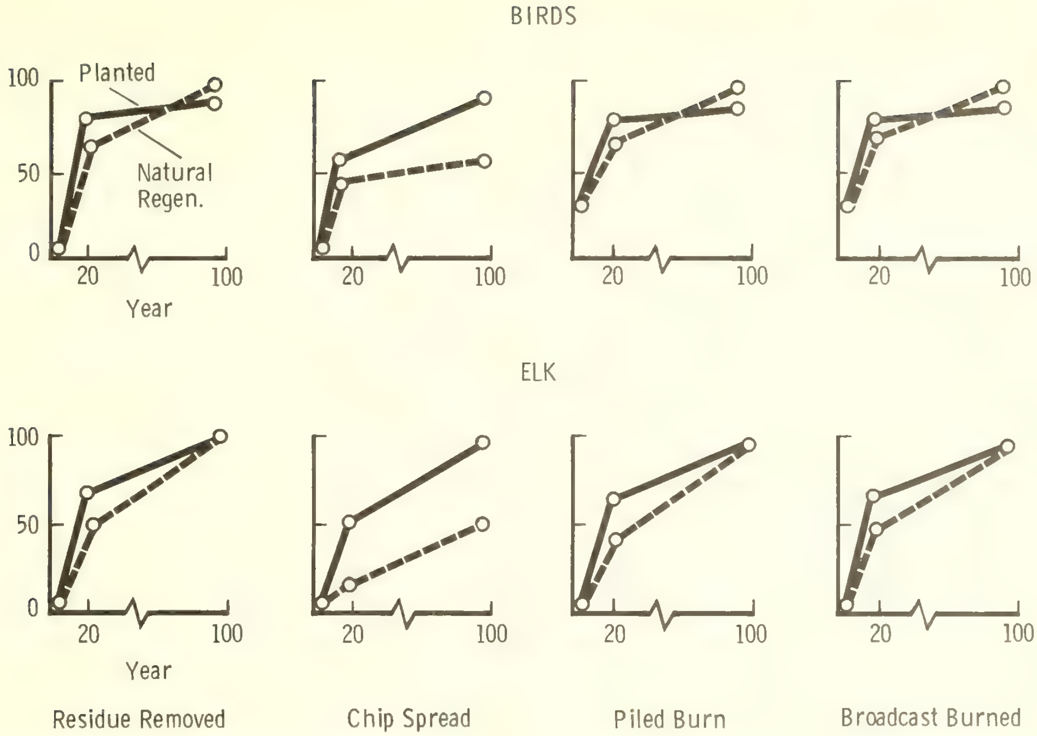


Figure 21.—Projected index of cover conditions for birds and elk, by treatment, 1, 20, and 100 years after harvest. (Source: G. Gruell, office report, Teton National Forest, June 15, 1973.)

For moose, elk, and deer there is little difference among treatments as to impact on cover. The uncut mature forest was given an index rating of 100 for cover, and initially after harvest all treatments rated 0 for big-game cover. Using projected vegetation growth 20 years after harvest when lodgepole regeneration is tall enough to provide cover, all treatments are rated 70 if planted and 50 if natural regeneration is used. The only treatment difference is in the chip-spread treatment where lodgepole regeneration would remain sparse and therefore cover rated only 10 even after 20 years.

If expected cover and forage responses are used as an index of the relative impact on the moose and elk component of wildlife, figure 22 shows the relative ranking of different treatments.

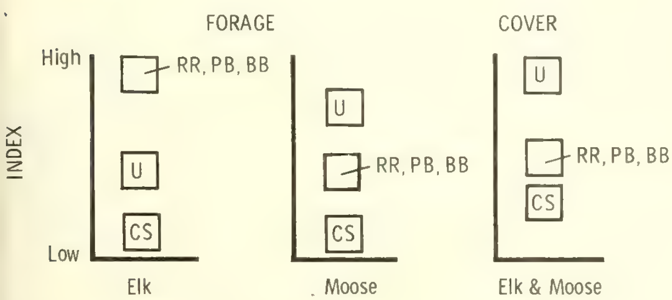


Figure 22.—Indexes of treatment effects on big game forage and cover at year 20.

As noted earlier, cover for large animals is important, but it does not respond differently among treatments. The "high-low" scale in figure 22 is not a precise measure, as are forage weights, but it provides a useful scale for the next step of analyses.

Birds.—Both small songbirds and larger birds of prey have a positive value to recreationists and for insect and rodent control. Some, such as juncos, may have a negative effect by feeding on tree seeds and newly germinated seedlings (Shearer 1976). In this analysis treatments that favor bird habitat or increase species diversity are considered positive. The preceding section reported species observed and expected trends in habitat for various treatments. An evaluation of these treatments using a 0-100 index is illustrated in figure 23.

Assuming an average value over the 20-year period gives the following annual rating for different treatments:

	Food	Cover
Pile/burn, broadcast burn	40	55
Residue-removed	30	40
Chip-spread	5	40

Because the relationship of food and cover is similar among treatments, it seems reasonable to combine both into a single composite index of bird use opportunity as in figure 23.

Pocket gophers.—There is little likelihood that pocket gophers would be exterminated from the area by any harvest treatment because they thrive on cutover lands. They kill small

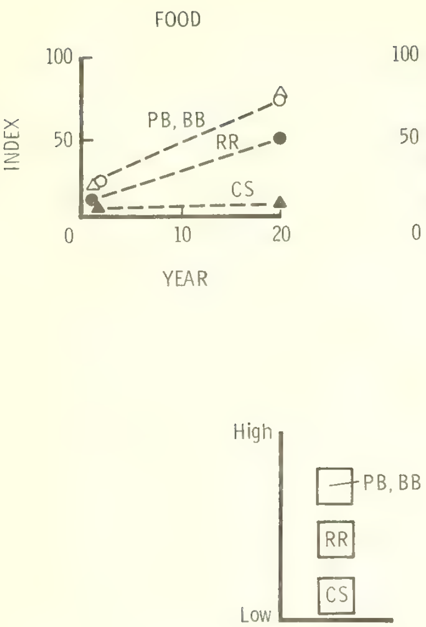


Figure 23.—Effect of treatments on bird habitat.

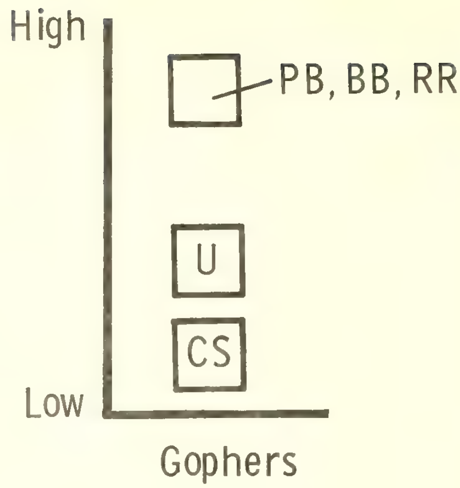


Figure 24.—Relative ranking of pocket gopher response to treatments.

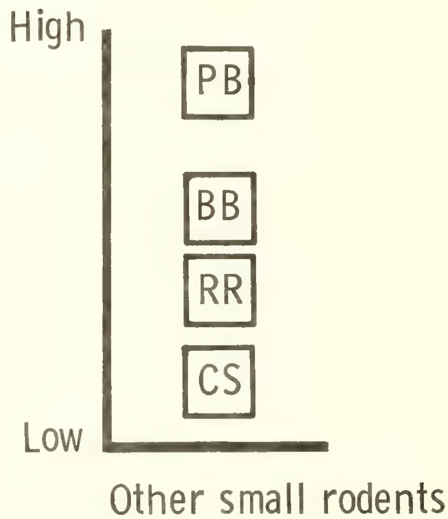


Figure 25.—Relative ranking of small rodent response to treatments.

trees, but are valuable as food for carnivores and raptors. In this assessment, treatments favoring gophers are judged to be undesirable. Gophers feed on understory vegetation, so high vegetation production favors gopher population. Using this as a basis, the net effect of treatment on gophers is as shown in figure 24. The chip-spread treatment rates low because understory vegetation is retarded and gopher food limited. Other treatments are all higher because they provide ample gopher food; uncut stands are intermediate.

Other small rodents.—Mice, voles, and chipmunks have a negative impact on trees and other vegetation. They also are prey for predatory birds and animals that are valued by recreationists (coyote, bobcat, raptors, and so forth). Also, some rodents such as chipmunks are themselves valued for wildlife observation. In this analysis, therefore, these rodents are considered of moderate value, and neither extinction nor explosive overpopulation is likely in any treatment.

The index of population differences reported in SECOND RESPONSES can be portrayed as in figure 25. For several species no evaluations or trapping were made but their response to different treatments can be approximated. Red (pine) squirrels and flying squirrels will be displaced from all treatments until lodgepole reaches pole size or larger. Snowshoe hare and porcupines will increase on all treatments after trees are sapling size or larger.

Grazing Values

To protect regeneration, cattle grazing is not usually allowed in cutting units that have been planted to trees. All units of the study were fenced, and cattle have been kept out. Usually grazing is deferred until trees are 6 to 8 ft tall. With 2-0 planting stock this takes about 10 years and, therefore, the amount of herbage produced after age 10 can be used as an index for comparing effects of treatment. The average amount of herbage produced per year for the period 10 to 25 years after harvest is projected to be:

Treatment	***Lb/acre***
Uncut	300
Residue-removed	650
Chip-spread	75
Broadcast burn	800
Pile/burn	700

These figures are derived by projecting the production for the study area as in figure 20 and averaging the annual production for the treatments for the period years 10 to 25. Although the residue-removed treatment initially produced more herbage than other treatments, by the 10th year all treatments except chip-spread are producing nearly the same.

In the case of forage for livestock, it is possible to convert forage production into a potential animal-unit-month (AUM) figure if the species, palatability, and nutritive value of the understory vegetation are available. These have not been determined specifically for the study area, but based on average forage values of similar vegetation elsewhere, and on estimates of forage availability, the potential for grazing can be expressed as in figure 26, using AUM's as the unit of value. AUM's are estimated from Forest Range Environmental Study (USDA Forest Service 1972) data which showed 288 lb/acre herbage average under lodgepole pine, and 152 acres/AUM. To simplify the comparisons, these values assume the cutover units are the only source of forage. Actual AUM/acre utilized would in practice probably be less than portrayed.

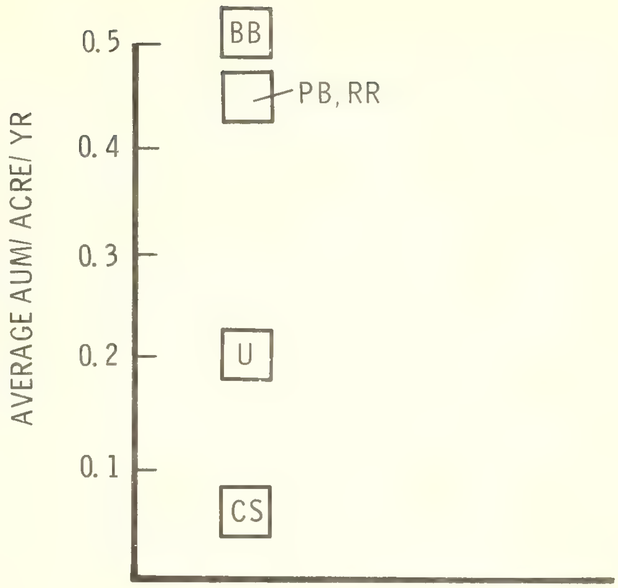


Figure 26.—Average AUM's per acre per year for the period 10 to 25 years after treatment.

Esthetic and Recreational Values

One objective of this study was to compare the logging and residue treatments in terms of esthetics. One phase of this evaluation was based on ratings given to color slides of the different treatments. The slides were taken from the viewpoint of an observer hiking or driving alongside the harvested units. In addition, managers evaluated how well each treatment might be suited to different recreation activities at the site. Distant-view esthetics, such as how well the shape or location of the units conformed to the general landscape, were not evaluated. Such considerations are, of course, important for any harvest operation.

PUBLIC VIEWER EVALUATION

The areas were evaluated using the Scenic Beauty Estimation (SBE) technique (Daniel and Boster 1976). Color slide photos of the areas were shown to panels of viewers who rated the slides on a scale of 0 ("dislike") to 9 ("like"). The viewers' ratings were mathematically transformed into scores that take into account the fact that some viewers use the rating scale differently than others. The transformed scores were then used to analyze the statistical significance of the ratings.

An arithmetic mean rating for each scene was also computed. The mean rating and the transformed score both indicate the same preference ranking among treatments. The arithmetic mean ratings are used here because they report results in the same units that viewers used in their ratings. Mean ratings for selected years after harvest were as follows:

	Panel "A"		Panel "B"		
	1st year	5th year	1st year	5th year	10th year
Meadow-forest edge (uncut)	-------7.43-------		-------------7.63-------------		
Residue-removed	3.09	3.61	3.35	4.39	4.62
Residue chipped and spread	2.71	2.25	2.11	2.71	4.31
Residue piled and burned	2.40	2.50	2.81	2.94	4.49
Residue broadcast burned	(not rated)	2.47	(not rated)	3.63	3.77

These are results from two of six panels that evaluated the treatments. Panel "A" did not evaluate the 10th year. Differences in means that exceed 0.86 for Panel "A" and 0.96 for Panel "B" are significant at 0.95 level.

Although ratings between panels are not statistically comparable, results were similar among all panels tested. A meadow-forest edge (not harvested), generally considered an appealing forest scene, was consistently rated much higher than harvested scenes. In the first year, all treatments were rated fairly low, with residue-removed somewhat higher. In the fifth year residue-removed was significantly higher, but in the 10th year all treatments were rated fairly close, and were significantly higher than earlier.

The SBE ratings do not reveal why the viewers initially rated the residue-removed treatment higher, or in year 10 other harvest treatments were about equal. However, other studies (Arthur 1977; Touzeau 1976) suggest two factors probably contributed. First, the residue-removed treatment had low (nearly ground level) stumps and large pieces of residue were absent, as compared with the higher stumps and partially burned large pieces in the burn treatments. Second, in the residue-removed units, roots and upper parts of forbs, grasses, and shrubs were left mostly intact and regrowth began to "green up" the area immediately. In the burn units this undergrowth was destroyed and in the chip-spread most was covered. By the 10th year understory vegetation and new seedlings were established, and covered much of the evidence of disturbance. New seedling growth was best in the pile and burn, and may have contributed to its improved rating in year 10 by screening the debris piles.

Figure 27 projects how esthetic rating might change over time, based on a separate study of viewer ratings (Panel "C") of slides of the study area and of lodgepole pine stands of different ages (Benson and Ullrich 1980). In this study the residue-removed treatment has some initial advantage over other treatments. When the young stands develop enough to cover any remaining logging debris or ground disturbance, the differences in ratings will probably diminish. The chip-spread areas were rated lower, and we would expect this to continue for as long as the chips retard regeneration. However, the combination of chip layer deterioration, moisture holding effects, and various changes in

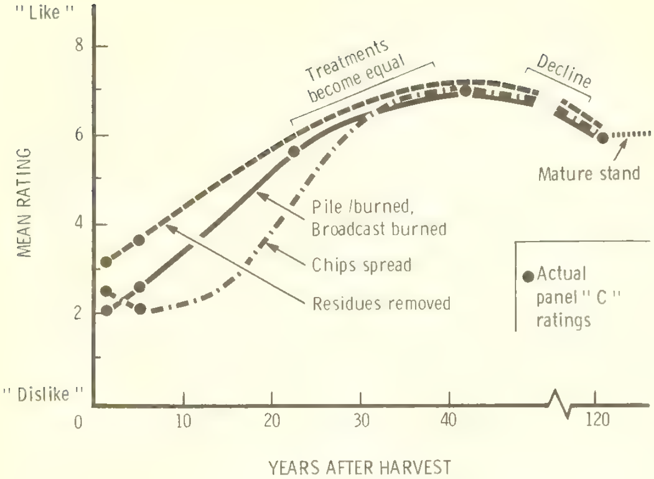


Figure 27.—Visual rating and projected trends for alternative residue treatments, lodgepole pine.

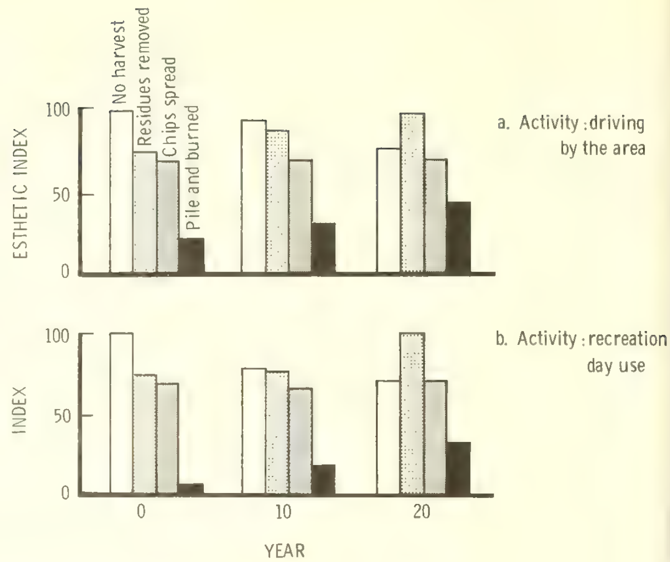


Figure 28.—Managers' evaluation of treatments for two recreation uses.

soil and water may alter this projected curve. In fact, the ratings by Panel "B" suggest differences have already notably diminished by the 10th year.

MANAGER EVALUATION

In a separate evaluation made the year after harvesting, Forest Service landscape managers appraised the treatments in terms of esthetics and recreation use, and rated the treatments on a scale of 0 to 100.[5] Evaluation for two typical recreation activities is shown in figure 28. In the pile/burn treatment, the activities that involved rapidly passing the area by car were rated higher than those where the viewer passed through more slowly. Lowest ratings for this treatment were for day-use recreation. Ratings for other recreation activities are in the appendix. In general, for a given treatment there was not much difference in the rating based on different type activities.

In addition to the rating immediately after harvest (year 0), projections were made as to esthetic response 10 to 20 years hence,[6] based on what would be seen driving by the areas. The ranking among treatments and the expected response over time were generally consistent with the SBE results obtained from the public viewer panels, even though the managers' evaluation preceded the SBE study by several years. Nevertheless, the managers' rating of residue-removed treatment was relatively higher than ratings by viewer panels.

Layout, location, and size of the cutting units were not directly part of the study, but under normal clearcutting practices, it is unlikely that different residue treatments would have much effect on general layout and design of cutting units.

The principal difference among the postharvest treatments is the proportion of the initial 20-year period that rates low on the scales. For the initial period of 20 years, a comparison of esthetic impact as a composite of both the managers' estimate of use opportunities and viewers' ratings can be portrayed as in figure 29.

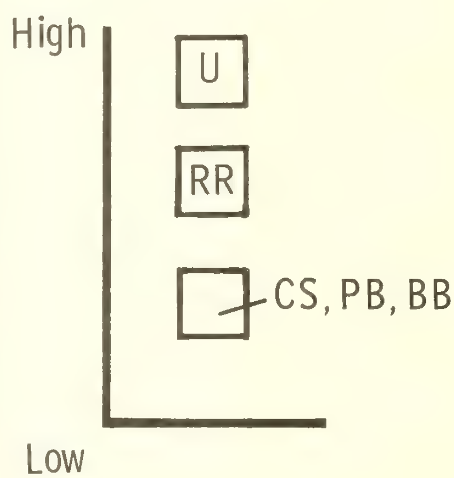


Figure 29.—Relative esthetic and recreation use opportunity.

Soil and Water

In the previous section, initial responses were compared in terms of soil and water chemistry, nutrients, and various soil properties. These factors work in combination to affect the basic condition of the site and its ultimate productive capacity.

Although there is a considerable background of information on soil productivity, depletion, and use (or abuse) regarding agricultural land, much less is known about forest land and the long-term effects of harvest and subsequent management activities. Because site factors are so complex, in many ways each

[5]Office report, "Wyoming Logging Residue Study—Esthetic and Recreation Evaluation," by Reed Stalder, USDA Forest Service. (On file at Forestry Sciences Laboratory, Missoula.) Activity viewpoints rated were: hiking-horseback, car travel, airplane, camping, from overlook, recreation day-use, and picture taking.

[6]Projections for 10 and 20 years hence were based on the expectation that plant succession and growth will be similar to that observed in adjacent areas following disturbance.

forest acre may be unique in its response to a given treatment. Furthermore, there is limited knowledge as to how sites change over time following harvest.

Despite the obvious limitations of a rather short-term study of treatments in one location, as this study involved, it is possible to hypothesize potential outcomes from the various treatments. The following section discusses this in terms of water, soil stability, nutrients, and site productivity.

Water quality.—As noted in the previous section, water quality was not substantially affected by the treatments. However, nitrates and phenols potentially could be of concern if they reach the aquatic environment or enter public water supplies in sufficient concentration. Also, erosion and siltation of streams would become important considerations if these treatments were applied on steeper terrain.

The most significant change in nitrates was in the pile/burn treatment, where levels in the soil solution increased to an average of 4.4 mg/liter, a fortyfold increase over the uncut forest. Although this level is not above the allowable threshold for potable water, the fact that nitrate levels can be changed so dramatically should serve to alert managers to the potential for pollution, and to the need to take this into account regarding the proximity of harvest units to ground or surface water that feed public water supplies.

In the chip-spread and residue-removed treatments relatively high phenol contents were present in the soil solutions during the first year, but declined sharply after that. If a cutting unit were located near a live stream and enough water were present to carry the phenols directly into the stream the first year, then potentially phenols would be present in amounts unacceptable for fisheries or water supplies.

The previous discussion of hydrology showed substantially higher soil movement in the scarified areas between burned piles (fig. 10). The terrain at the study site would result in virtually no chance for this to cause turbidity in any live water courses, but in steep terrain with more erodible soils, scarifying from logging can be a major source of silting in streams and turbidity of water. Soil movement was observed at the research plots under water applications that would correspond to cloudburst conditions, and the soil appeared to be moved only short distances within the site. This suggests that the pile/burn treatment might be considered slightly less desirable than the others in its impact on water quality for gentle terrain, but of more concern to water resource management under steeper conditions.

Site productivity.—It does not appear that the small amount of soil erosion, the nutrients lost in solution and in eroded soil from these treated sites, or the interruption of nutrient cycling will have a significant effect on growth rate or nutrition of the next crop of lodgepole pine. Over several centuries and many tree crops, however, enough nutrients might be lost through removal of residues to affect site quality. The greater the amount of material removed and utilized in a forest crop, especially if it is bark, needles, twigs, and seeds, the greater will be the quantity of nutrients removed from the site.

These factors raise two considerations regarding overall site productivity. First, early survival and growth of lodgepole pine is less on both the residue-removed and chip-spread treatments, and while the cause cannot be established from these studies, the increased level of phenolic compounds from these treatments suggests this could be a contributing factor. Second, and of a longer term nature, while a single harvest treatment does not appear to affect nutrients, repeated and intensive removal of biomass might. What this may mean from a practical standpoint is that no single factor—nutrients, phenols, soil movement, microsite effects, soil structure, or microorganisms—appeared to reach critical levels in this study situation. But if logging operations and residue treatments were applied in such a way that all the negative factors worked in concert, and were repeated through several cycles, long-term adverse effects to the site might result.

Because of the complexity and uncertainty posed by the long-term nature of these factors, it is highly speculative to compare treatments. Based on initial findings, however, treatments might be ranked on an index basis as in figure 30. The chip-spread and residue-removed treatments are rated slightly lower for water quality than the pile/burn because it is assumed that if some phenols did enter live water it would probably cause more concern than would the presence of some turbidity from soil movement. For overall site productivity, broadcast burning (which is close to natural burning conditions) is somewhat better than pile burning from which high nitrate levels and some soil loss may occur. Residue-removed and chip-spread rates were lower because of observed initial and potential long-term effects.

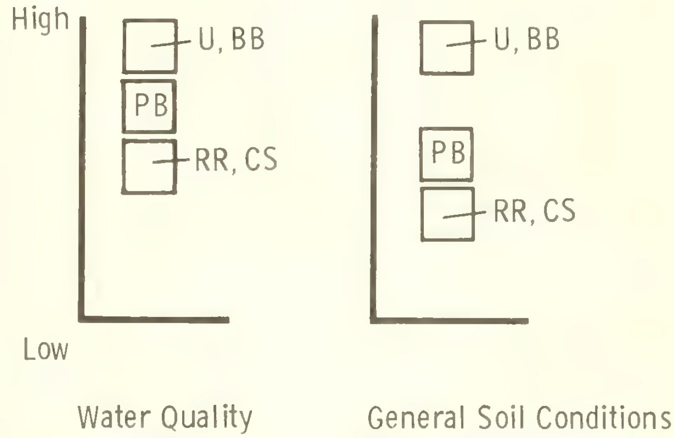


Figure 30.—Site response to alternative treatments.

Timber

The previous sections summarized harvesting activities and the regeneration, survival, and early growth of lodgepole pine after harvest. The immediate impacts of the alternative study treatments can be compared in terms of costs and returns for these activities. These are discussed in detail in the next section.

The stand projections presented earlier give an estimate of the kind of timber resource that will be grown for the next harvest. These projections indicate a considerable range in the nature of alternative future crops, with large cubic volumes in many small stems or fewer stems grown to saw log size (figs. 17 and 18; tables 14a and 14b) as potential outcomes.

Between these two time periods—the current, measurable results and the projected future harvest period 80 to 100 years hence—many uncertainties might alter the timber management situation (fire, disease, etc.). These have been alluded to in other sections. In addition, the stand may require thinning or other cultural work. Although no specific study was made, the different treatments have characteristics that are certain to influence intermediate cuttings. A high level of natural stocking is developing in the pile and burn treatments, not only in the

Table 15.—Net dollar values per acre of harvest and regeneration activities (1980 dollars)

		Uncut	Residue-removed	Chip-spread	Pile/burn	Broadcast burn
Timber value	Saw logs	0	1,994	1,994	1,994	1,994
	Chips	0	664	0	0	0
Subtotal		0	2,658	1,994	1,994	1,994
Harvest cost	Saw logs	0	725	725	725	725
	Chips	0	[1]705	[2]0	0	0
Subtotal		0	1,430	725	725	725
Net timber value		*0*	*1,228*	*1,269*	*1,269*	*1,269*
Slash treatment		0	0	[2]705	78	33
Planting		0	281	261	239	220
Fencing and rodent control		0	115	115	115	115
Subtotal		0	396	1,095	432	368
Net dollar value		*0*	*832*	*174*	*837*	*901*

[1]Chip cost treated as harvest cost because chips are recovered as a product, but could be considered as slash treatment.
[2]Cost of chipping is assigned to slash treatment because the residue stays onsite.

natural regeneration portion but in the seed spot and planted portions as well. If overstocking develops, projections based only on planted and seed spot stocking would be altered, and there may be a need for precommercial thinning.

Second, if there is a need for thinning or other stand entry, the method of slash disposal from the previous harvest may have a pronounced impact on the activity. The broadcast-burn units in particular were viewed as posing considerable difficulty for mechanical and possibly for manual thinning due to the large amount of charred residues remaining.[7] The same is true (but to a lesser extent) for the windrowed slash. This problem may tend to be aggravated by the fact that conditions for broadcast burning are not always ideal. The manager faces a high probability of either poor burning conditions that result in large amounts of unburned slash, or very dry conditions that threaten costly escaped fires. These factors are not an indictment of broadcast burning. Rather, they are considerations that could not be analyzed within the scope of the study.

The study area is typical of high elevation lodgepole pine and is not much affected by bark beetle infestations or dwarf mistletoe. Although many of the findings of this study, such as logging, utilization, and regeneration, may apply in other areas, the potential interaction between the treatments studied and insect and disease factors is not addressed.

Costs and Returns

Because of the uncertainties of future stand development and future costs and values, current costs and returns are used as a basis for comparing the different treatments. This analysis assumes that timber will be harvested on a 100-year rotation and therefore the dollar values are converted to a per-year basis; that is, the assumption is made that a continuing program of harvest would be followed and that for any given acre the net values per year would be the totals that accrue during a rotation, divided by 100 years.[8] Under these assumptions, the total costs and returns from the timber harvest, postharvest, and regeneration activities reported earlier are as shown in table 15. As noted in previous discussion, these costs are adjusted for initial stand volume differences, and updated to 1980 dollar basis.

Grazing, the one output in addition to timber that provides market values, is included in the cost and return summary. Grazing values are based on the projected understory vegetation development and are assumed to be harvested annually. In order to estimate grazing values, the average forage weights per year in each treatment are converted to animal unit months using the assumptions in the appendix. In this case, the assumption was made that, during a rotation period, any given acre will provide the following:

Year 1 - 10 = no forage or AUM's, since no grazing was allowed
Year 11 - 25 = forage and AUM's per year estimated from projections by treatment
Year 26 - rotation age = forage and AUM's estimated for mature lodgepole pine

[7]Based on communication from George Roether, R-4 Timber Management, and comments of other participants following field examination of the study sites in a workshop held in August 1981.

[8]It should be noted that for some purposes, an investment analysis that either compounded costs such as regeneration, or discounted future values, might be made.

Assuming a 100-year rotation, and the vegetation weights and AUM's, the total value per acre in grazing for the 100-year period is:

Uncut	$39.00
Residue-removed	42.00
Chip-spread	31.00
Pile/burn	43.00
Broadcast burn	45.00

There is not much difference among treatments in the grazing values because for so much (75 years) of the 100-year period, forage is at the level of uncut forest.

The timber and grazing values can be combined to produce a total net dollar value for the period. Alternatively, since nondollar values such as wildlife and esthetics are "produced" every year, the dollar values can be converted to an average annual value to provide a more equitable basis for comparing dollar and nondollar values. Total and average annual grazing and timber net values are:

	Value/acre 100-year period			Annual
	Timber	Grazing	Total	(Total ÷ 100 yrs)
	Dollars/acre			
Uncut	0	39	39	0.39
Broadcast burn	901	45	946	9.46
Pile/burn	837	43	880	8.80
Residue-removed	832	42	874	8.74
Chip-spread	174	31	205	2.05

These annual costs and returns can be portrayed on the high-low scale as in figure 31. The net values represent the average annual return per acre, with costs and returns treated as current. As noted earlier, if some or all of the costs or returns were compounded or discounted, as in an investment analysis, the relationship of values could be different.

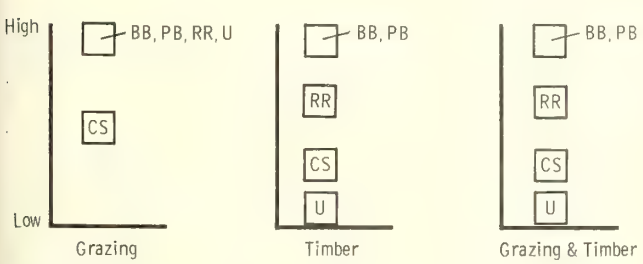


Figure 31.—Index of net dollar returns per acre per year.

MANAGEMENT IMPLICATIONS

If all the resources, harvest alternatives, and outcomes could be expressed in dollar values, it would be possible to extend data from the previous sections and derive a final comprehensive net value that could serve as a measure for comparing the harvest treatments. Unfortunately, many of the responses and use opportunities are not readily expressed in dollars. Furthermore, even the indexes developed may have different weights from one situation to the next, depending on which is of primary concern in the area. It is not possible to sum up the findings in such a way that the "best" harvest alternative is automatically identified. Nevertheless, two methods are presented for extending the analyses of nonmarket values and resource impacts to other situations.

Comparing Alternatives Using Net Dollar Returns and Nondollar Indexes

Harvesting alternatives in this study have resulted in different physical, biological, and net dollar return outcomes as described earlier. These dollar returns and indexes of nondollar responses can be compared as in figure 32 (Rickard and others 1967). The net dollar returns on the left are expressed as the net returns per acre per year, as derived in the previous section. On the right are the indexes of the various resources as use opportunities.

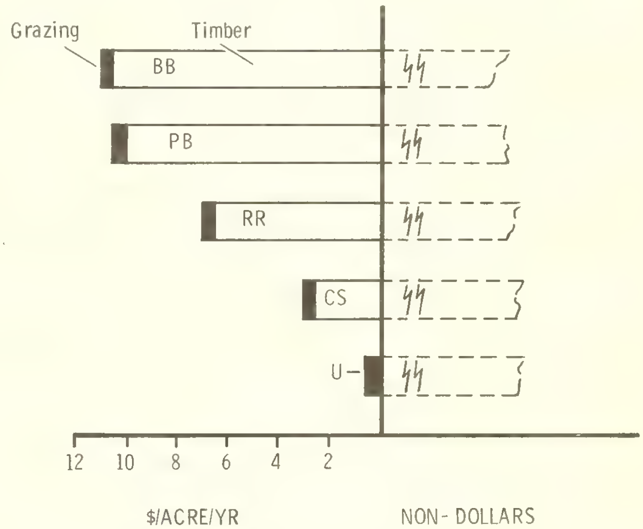


Figure 32.—Comparison of net dollar values of timber and grazing with nondollar values.

Visual comparison indicates that, considering one nondollar resource at a time, some alternatives are clearly superior to others even though the value of the noncommodity resources is not known. For example, in figures 33 through 35, broadcast burn is superior to every alternative except uncut, when considering small animal and bird habitat, water, and big-game cover. This is evident because both the dollar and nondollar bars either equal or exceed those of the other three alternatives. In the case of esthetics (fig. 36), pile/burn and chip-spread are inferior, but the other three alternatives are viable in that they represent trading off of net dollars against esthetic gains.

These comparisons do not by themselves indicate the best opportunity. For example, if harvest is planned, then the uncut option is not relevant even though it maximizes all of the nondollar values, at least in the short run. Nevertheless, to the extent realistic indexes can be developed, this analysis can compare dollar and nondollar outcomes for any individual use opportunity or resource.

Tradeoffs Among Alternatives

Although the analysis above illustrates the dollar and nondollar consequences of harvest alternatives for individual uses, frequently the interaction of several nonmarket values must be

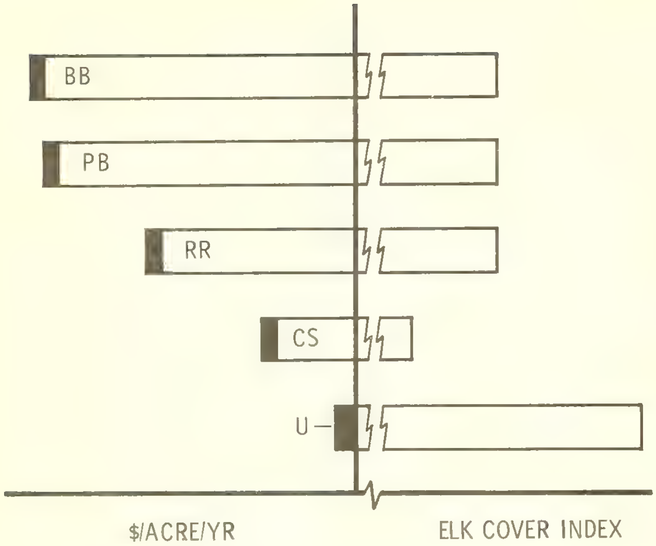


Figure 33.—Dollars and elk/moose cover.

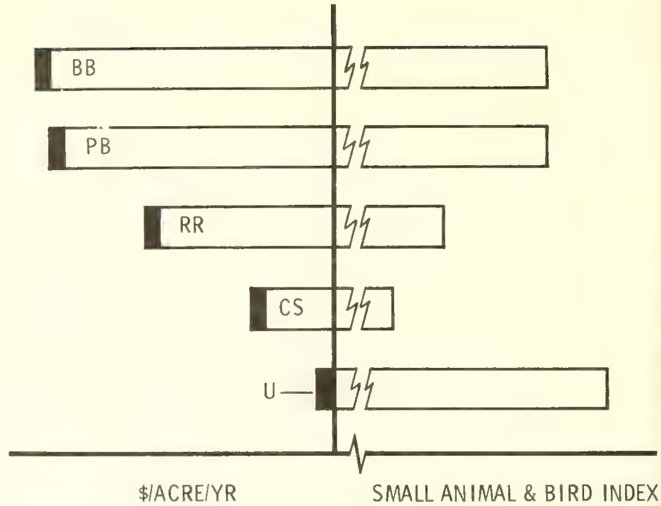


Figure 35.—Dollars and small animals and birds.

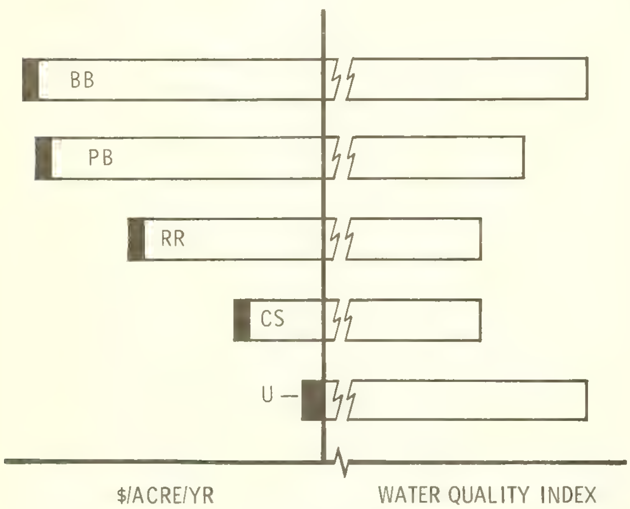


Figure 34.—Dollars and water quality.

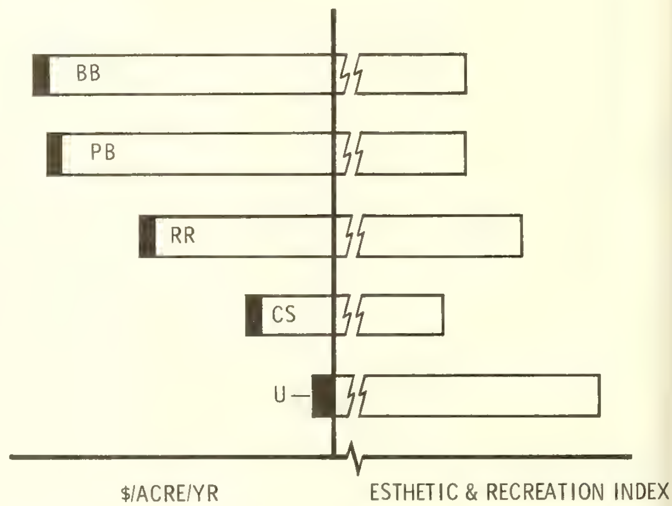


Figure 36.—Dollars and esthetics and recreation.

taken into account when analyzing harvesting alternatives. To take these into account in this study, the following steps are developed:

1. Identify potential interactions among uses.
2. Identify those interactions that might be affected by residue treatment.
3. Describe the interactions identified in 2 above in terms of tradeoffs.

Interactions between use opportunities that typically occur in a lodgepole pine situation such as the study area are summarized in table 16. The use being produced is listed across the top, and the use affected by the outputs is in the left column. Each cell in the matrix describes the nature of the interaction. For example, if an area is being used to produce timber (column 1), all other uses are affected by the amount and pattern of harvest, site preparation method used, and density of the newly developing forest. Water, on the other hand, may produce no appreciable impact on timber or grazing but can affect aquatic wildlife in terms of volume of runoff, its timing, and water quality.

Not all of the interactions are related to treatment differences. For example, in producing timber the harvest pattern (location, size, shaping, percent of area being harvested) affects all use opportunities, and may in fact, be the most important impact of harvesting. It is not analyzed here, however, because harvest pattern is not basically determined by residue treatment.[9]

Similarly, water is affected by grazing, wildlife, and recreation especially in the riparian zone, and since most timber harvest in this area is not now conducted in the riparian zone this interaction is not analyzed. Water may, however, be affected by timber activities, such as site preparation, or residue treatment. Earlier

[9]In other situations, residue treatment decisions might affect shape and location of cutting units; for example, broadcast burning in steep country where fire control is more difficult.

Table 16.—Interactions between use opportunities in a typical lodgepole pine forest

Each cell contains items, activity, or units involved in the interaction

USE BEING AFFECTED (to these)	USE BEING PRODUCED (from these)				
	TIMBER	**GRAZING**	**WILDLIFE**	**WATER**	**RECREATION**
TIMBER	X	AUM's year month	Gopher population Rodent population Seed-eating birds	Minor	Esthetics
GRAZING	Harvest pattern and percent of area Site preparation Tree density	X	Big game population Gopher population Rodent population	Minor	Disturbance to herd (function of people numbers)
WILDLIFE	Harvest pattern and percent Site preparation Tree density	AUM's year month	X	Volume Quality for aquatic life Timing	Disturbance Hunting
WATER	Harvest pattern and percent Site preparation Tree density	Temperature Chemistry (in riparian zone)	Temperature Chemistry (in riparian zone)	X	Temperature Chemistry (in riparian zone)
RECREATION	Harvest pattern and percent Site preparation Tree density	AUM's year month	Big game hunt Nongame species, numbers (bird watch, etc.)	Volume Quality Timing	X

Example of using table: **WILDLIFE** (being produced) interacts with **TIMBER** (being affected) in terms of gopher, other rodent, and seed-eating bird populations; but **TIMBER** (being produced) affects **WILDLIFE** through harvest patterns, percent of area cutover, site preparation method used, and density of trees.

sections presented some differences among treatments in their effect on water quality.

Some use opportunities that are most directly related to residue treatment and regeneration are listed in table 17, which describes the general nature of the interactions—competing, complementary, or both.

Using the high-low scales developed earlier, it is possible to show resource use opportunities for different combinations of resources under alternative treatments. In figure 37, four extremes of treatment alternatives are shown (that is, widely different combinations of resource use opportunities resulting from different treatments).

Generally, any array of treatments that falls along the line between a and b are complementary; both use opportunities are increased. Treatments along the line between x and y are competing; some of one use opportunity is given up to increase the other use opportunity. All other things being equal, the best treatment is one in which both use opportunities rate high (as treatment b); the worst is when both rate low (as treatment a). When the alternative treatments are arrayed along the x-y line, a decision must be made as to which is the better alternative. This may be based on comparing net dollar values of each, or the criteria may be more complex, involving some threshold of environmental acceptability or an amenity value, such as visual quality or songbirds. Thus, the comparisons shown in figure 37 can illustrate how indexes of resource use or response relate to each other, but may not provide dollar values or even a valuation scheme for some outputs.

In table 17 timber was identified as a use that interacts with all other resources and uses. Using net timber dollar values as an index, the interaction of timber with other outputs can be portrayed as in figure 38.

The "uncut" option rates low for timber because no wood is produced. Chip-spread is somewhat better because saw log values were recovered but the cost of chipping was incurred. Residue-removed is higher because some chip values are recovered to offset chipping costs. Pile/burn and broadcast burn rate highest.

The ratings for other resource uses are arrayed along the horizontal axis of figure 38. For small wildlife, pile/burn and broadcast burn are the best treatments in that they provide high use opportunities for both timber and small wildlife. For water, broadcast burn and uncut rate high, but others have some potential for adverse effects.

Timber vs. recreation esthetics represents a competing situation, at least in the short term. Uncut mature timber is clearly the best esthetic treatment; pile burning the worst esthetically but the

Table 17.—Interaction of use opportunities related to residue and regeneration treatments

Use being produced	Use being affected	Effect of residue/regeneration treatment on interaction
Timber	Grazing	**Competing** - (a) Treatments resulting in early, dense, and vigorous tree regeneration reduce grazing. (b) Fencing to protect trees reduces grazing.
	Wildlife (elk-deer-moose)	**Competing** - Regeneration reduces forage. **Complementary** - Regeneration increases hiding cover.
	Wildlife (small mammals and birds)	**Competing** - Treatments resulting in quick revegetation may attract rodents and require rodent control to protect trees. **Complementary** - Treatments providing predatory bird habitat may achieve balanced wildlife.
	Water (and aquatic life)	**Competing** - Burning or scarifying favors regeneration but adds turbidity/chemicals to water **Complementary** - Treatments resulting in quick, vigorous regeneration reduce water yields to the level of yields of uncut forest.
	Recreation	**Competing** - Initial site preparation by burning increases tree regeneration but decreases esthetics; residue-removed reduces tree revegetation. **Complementary** - Vigorous tree cover improves esthetic qualities.
Grazing	Timber	**Competing** - Methods that enhance forage and reduce trees extend grazing and decrease timber.
	Wildlife	**Complementary** - Methods producing forage favor large mammals. **Competing** - Methods enhancing grazing may reduce big-game use by "social" crowding.
Wildlife	Timber	**Competing** - (Timber vs. Wildlife above)
	Grazing	**Competing and Complementary** - (see above)
	Recreation	**Complementary and Competing**
Water	Wildlife and recreation	**Indeterminant** - All residue treatments have potential adverse effects.
Recreation	Timber	**Competing** - Most immediately acceptable esthetic treatment, residue-removed may retard regeneration/growth. **Complementary** - More rapid regeneration/growth of trees speeds up esthetic response in the long run.

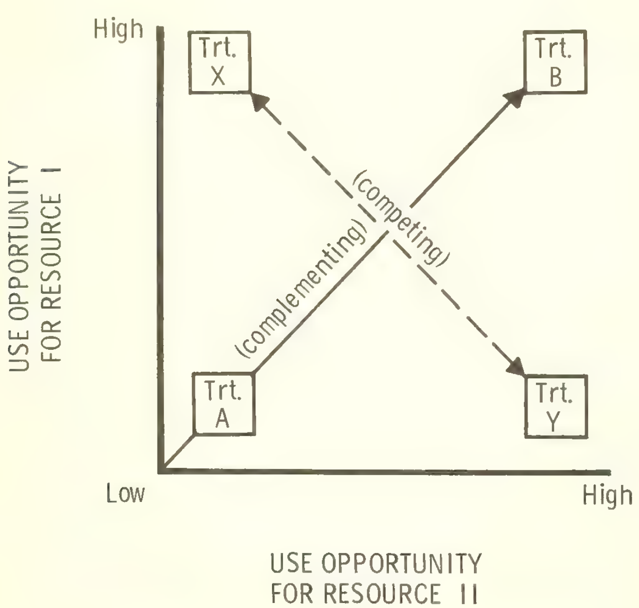


Figure 37.—Resource use opportunities under alternative treatments.

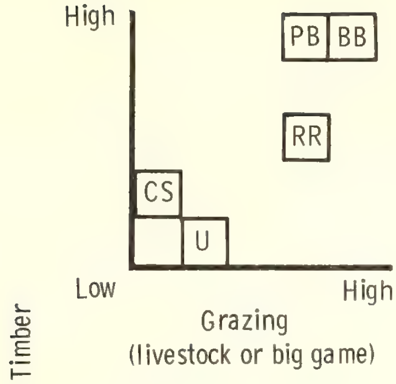
best for timber. (Note that the comparisons pertain to the first 25 years after treatment and, therefore, the attractive "greening" of young pole stands is not reflected.)

In this situation, the manager of a highly sensitive visual area may opt for no harvest or for removing residues with residue-removed utilization, regardless of the timber values foregone. In another situation he may decide higher timber values gained through burning residues can justify some loss of esthetic quality.

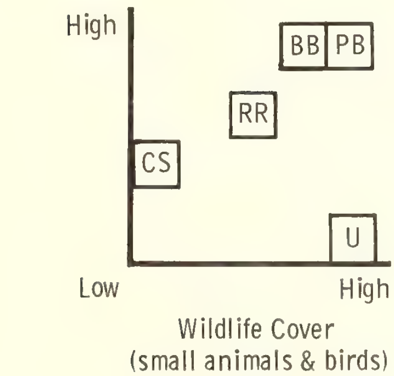
For big-game animal forage there is an indeterminate relationship with timber. Pile/burn and broadcast burn are fairly high in both outputs; chip-spread and uncut stands are relatively low, and residue-removed is intermediate.

Figures 39 and 40 portray the typical relationship between other resources as listed in table 17. Even without attempting to weigh the various outputs, these figures illustrate that some treatments are obviously superior to others for given resource combinations. For example, if timber revenues and wildlife cover are the two most critical resource outputs, it is obvious that pile/burn and broadcast burn provide more of both than any of the other treatments.

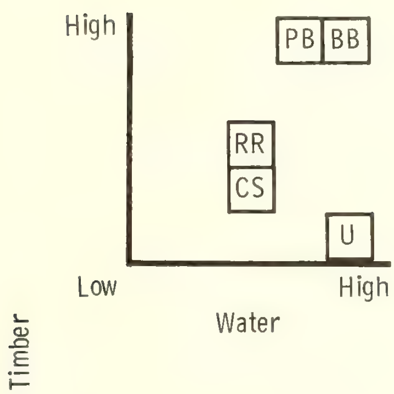
Timber revenues and esthetic quality present a different situation. Here all treatments except chip-spread fall along a "competing" or "tradeoff" line. Moving from uncut, which is high in esthetic quality and low in timber revenues, sacrifices esthetic value to gain timber value. Chip-spread, which lies closer to the



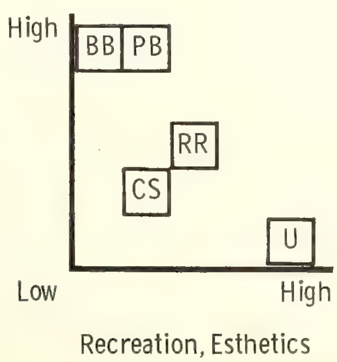
a. Cattle, large animals and vegetation- eating rodents are favored by BB which has the highest forage output.



b. Small animals and birds have better cover where some debris remains.



c. Piling has some negative potential for nitrates and turbidity. RR and CS have some potential for phenols in water.



d. Most treatments align as competing.

Figure 38.—Interaction of timber and other outputs.

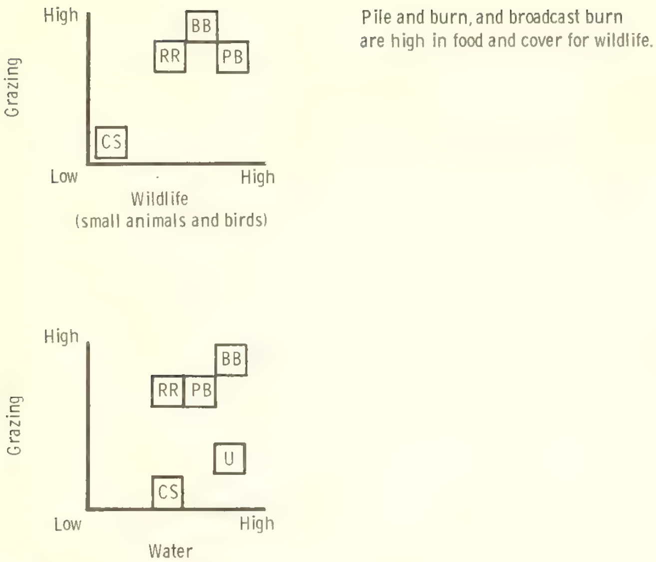


Figure 39.—Interaction of grazing and other uses.

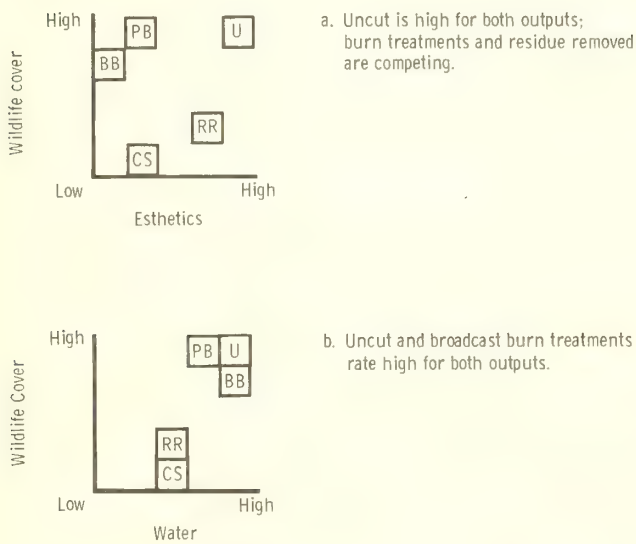


Figure 40.—Interaction of wildlife with other resource outputs.

lowest point on both scales, is clearly inferior; it can provide more recreation value than the burn treatments, but the residue-removed treatment provides even more recreation value plus high timber revenues.

Figure 40a shows a different situation; uncut is clearly superior for both wildlife and recreation, but burning and residue-removed are competing. In 40b, uncut and broadcast burn are both slightly better than pile/burn, and all three are definitely superior to chip-spread and residue-removed if wildlife and water are the concern.

These simple graphic comparisons are useful only if in fact they reflect realistic situations. Recalling that the slightly negative impacts on water quality were based on the small chance that turbidity, nitrates, or phenols would reach live water in level land, it may be more realistic to rate all treatments at the highest end of the scale (no negative impacts). In this case, water could be omitted as a basis for comparison. Conversely, on steep ground or near water courses where any pollutants are unacceptable, all treatments may be rated low on the water scale.

In addition, some treatments may not be relevant. In the wildlife-recreation combination the uncut stand is clearly superior. If the decision has already been made to harvest, however, then the next best options are among pile/burn, broadcast burn, or residue-removed, which are along the tradeoff line.

As in all analyses that are aimed at aiding decisions, this simple process is useful only to the extent assumptions are valid and conditions remain stable. The ultimate decision is up to the manager, and part of his decision process should be to speculate on the sensitivity of the analyses to change, probabilities of projected outcomes, and other factors not included in the analyses model. For example, the real probability of achieving a successful broadcast burn under normal day-to-day operations may be low enough that the manager would opt for pile burning even though the net timber values are less. Or, the value of residues may rise to the point that removing them becomes a more attractive alternative in the tradeoff analyses.

Summary of Treatments

This report describes harvest and regeneration alternatives and analyzes their impacts, as observed on the study site. In addition, the effect of treatments on several principal resources and use opportunities has been described, and interactions and tradeoffs identified.

There is no single "best" alternative among those studied; a treatment that benefits one resource may be adverse for another resource. The brief summary of each treatment that follows is, however, based only on the effects on individual resources, not on tradeoffs and interactions. In addition, the summaries include comments on some aspects that were not formally studied, but that have been identified as potentially important considerations in appraising the treatments.

PILE/BURN

Pile/burn, the standard conventional treatment of logging residues in the area, produced the most successful regeneration. It rated high in net timber revenues from harvest and in projected future stand volume. Scarification between piles resulted in more potential for erosion and removal of organic material and surface soil may reduce site quality between piles. A moderate amount of understory vegetation was produced in the first years after harvest and, together with debris in the piles, provided food and cover for small birds and ground-dwelling rodents (gophers, mice, etc.). The visual impact is harsh, and this appears to persist as long as partially burned piles are visible.

BROADCAST BURN

For the most part broadcast burning is similar to pile/burn, except net timber revenues are slightly higher because of lower slash disposal costs. Visual impact and wildlife cover and forage were about the same as with pile/burn. There was less soil compaction and surface erosion, but most soil nutrients and organic matter were similar to the pile/burn treatment except that nutrients were not concentrated into piles. Survival and growth of planted seedlings and of natural regeneration was slightly less successful than in the pile/burn treatment, but spot seeding success was higher.

Projected future stand development is about the same as pile/burn. The persistence of partially burned large residues over the area could adversely affect future stand entry for thinning or other management needs.

RESIDUE-REMOVED

In the actual study there was no available market for residues chipped onsite, but assuming a chip market and average chip price, the net timber revenues of this treatment are about the same as with broadcast burning. One notable effect of this treatment was substantially less success of planted seedlings and seed spots than the burned treatments, but good natural regeneration. There was more understory vegetation in the years immediately after harvest, but the absence of logging debris means less cover for wildlife. This treatment rated highest in visual preferences up through the fifth year after harvest. Phenol concentration in soil water was quite high under this treatment during the first year, but declined rapidly.

CHIP-SPREAD

Chip-spread had substantially lower net timber revenues because the cost of chipping was incurred but no chip values were received. Survival and growth of planted trees and seed regeneration was drastically impaired the first years, but growth of surviving trees has since mostly recovered. The projected future stand has fewer but larger trees, and volumes similar to other treatments. Understory vegetation is virtually absent the first 5 years and, therefore, wildlife habitat for all species severely impaired. The visual quality of this treatment was slightly better than burn treatments initially, but has not improved much since. Phenol concentrations increased markedly during the first year, and could affect water quality if this treatment were near running water courses. Potential for overland flow and erosion is virtually nil.

An Update and Overview

In the decade since this study was initiated, three major changes have occurred that bear on the interpretation and extrapolation of the study results:

1. The utilization of dead material that constituted much of the residues on the study site and in all overmature lodgepole stands, has greatly expanded both for round wood and sawed products. The effect on net timber revenues varies, depending on local markets and value of dead material, but generally revenues from saw logs and residues would be higher for all treatments if the study were conducted today.

2. The dramatic increase in fuel costs reduces the feasibility of chipping residues and spreading back on the ground. Although no direct estimation was made of fuel consumption, it is likely that skidding residues to the chipper, chipping, and then some additional spreading would consume more fuel than the single step of piling residues or broadcast burning.

3. Withdrawal of some forest lands from the timber-growing base and other constraints has increased interest in improving productivity on those lands managed for timber. Two important questions remain unanswered. First, the actual growth and development of the new stands on the different treatments: initial differences are expected to diminish, but only continued observation will verify this. Second, the need for and costs of thinning or other work can only be speculated at this time. As noted earlier, the broadcast-burn treatment had many favorable results, but could potentially increase costs of next entry. This is an important speculation that should be pursued. The chip-spread treatment appears to impair initial stand development, but if projected stocking prevails, it could reduce the need for intermediate thinning. Again, verifying this speculation and comparing costs and benefits is an important but yet unanswered part of evaluating this type of residue disposal.

In summary, then, this study has provided some initial evaluations of four residue treatments and three regeneration methods, but continued monitoring of the study area is needed to complete the evaluation and draw additional management information.

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Table 18.—Number of trees per acre, preharvest, by species, diameter class, and condition

	Unit 1	Unit 2	Unit 3	Unit 4
	Number of stems			
Live trees < 5 in d.b.h.				
Subalpine fir	300	474	236	277
Engelmann spruce	48	39	72	300
Lodgepole pine	420	39	54	108
Whitebark/limber pine	1,176	1,548	1,482	731
Subtotal, per acre	1,944	2,100	1,844	1,416
(per hectare)	(4 802)	(5 187)	(4 555)	(3 497)
Live trees 5.0 in - 8.9 in				
Subalpine fir	17	8	20	20
Engelmann spruce	21	4	13	6
Lodgepole pine	74	131	59	53
Whitebark/limber pine	0	0	5	11
Subtotal, per acre	112	143	97	90
(per hectare)	(277)	(353)	(240)	(222)
Live trees 9.0 + in				
Subalpine fir	4	7	16	16
Engelmann spruce	2	3	10	36
Lodgepole pine	172	212	155	90
Whitebark/limber pine	0	18	2	7
Subtotal, per acre	178	240	183	149
(per hectare)	(440)	(593)	(452)	(368)
Total live, per acre	2,234	2,483	2,124	1,655
(per hectare)	(5 518)	(6 133)	(5 246)	(4 088)
Dead trees, < 5 in	48	10	0	8
Dead trees, 5.0 + in				
Lodgepole pine	119	132	54	50
Other	0	0	2	5
Total dead, per acre	167	142	56	63
(per hectare)	(412)	(351)	(138)	(156)

Table 19.—Preharvest volume by component and cutting unit

	Conventional util			Residue-removed		
	Unit 2	Unit 3	Average	Unit 1	Unit 4	Average
Live, standing, to 6 in-top, ft³/acre	7,167	6,131	6,649	5,912	5,184	5,547
Dead, standing, to 6 in-top, ft³/acre	1,016	1,120	1,048	1,014	1,064	1,039
Subtotal, to 6-in top, ft³/acre	8,183	7,251	7,717	6,926	6,246	6,586
(m³/ha)	(573)	(508)	(540)	(485)	(437)	(461)
Tree residuals,[1] ft³/acre	1,460	797	1,128	1,124	752	938
(m³/ha)	(102)	(56)	(79)	(79)	(53)	(66)
Down, ft³/acre	1,182	1,478	1,330	1,820	2,482	2,151
(m³/ha)	(83)	(103)	(93)	(127)	(174)	(151)
Total, 3+ in, ft³/acre	10,825	9,526	10,175	9,870	9,480	9,675
(m³/ha)	(758)	(667)	(712)	(691)	(664)	(677)

[1]Includes total volume of trees 3.0 in (7.6 cm) to 6.4 in (16.4 cm) d.b.h.; plus volume between 6.0 in (15.2 cm) and 3.0 in (7.6 cm) top, for trees 6.5 in (16.5 cm) d.b.h. and larger.

Source: Gardner and Hann 1972

Table 20.—Preharvest volume by merchantability group

	Conventional util			Residue-removed		
	Unit 2	Unit 3	Average	Unit 1	Unit 4	Average
Merchantable						
Live, to 6 in-top, ft³/acre	7,167	6,131	6,649	5,912	5,182	5,547
Dead, to 6 in-top, ft³/acre	1,016	1,080	1,048	1,014	1,064	1,039
Total, ft³/acre	8,183	7,211	7,697	6,926	6,246	6,586
(m³/ha)	(573)	(505)	(539)	(485)	(437)	(461)
Saw logs, M bd.ft./acre	24.9	22.0	23.4	20.5	18.7	19.6
Residues						
Tree residual						
Green, ft³/acre	975	672	824	707	643	675
Sound dead, ft³/acre	485	123	304	312	24	168
Down, sound, ft³/acre	509	629	569	965	955	960
Subtotal	1,969	1,424	1,697	1,984	1,622	1,803
(m³/ha)	(138)	(100)	(119)	(139)	(114)	(126)
Unsound, ft³/acre	673	890	781	960	1,612	1,286
(m³/ha)	(47)	(62)	(55)	(67)	(113)	(90)
Total, 3+ in, ft³/acre	10,825	9,526	10,175	9,870	9,480	9,675
(m³/ha)	(758)	(667)	(712)	(691)	(664)	(677)

Table 21.—Weight of fine material: Preharvest

		Dry weight of material, tons/acre (t/ha)								
		Tree crowns[1]								
Unit	Size	AF	ES	LP	WB/LP	Total	Down[2]	Duff[3]	Understory[4] vegetation	Total all fines
1	Foliage	0.572	0.397	1.788	0.002	2.759				
	0'' - ¼''	.320	.218	1.565	.002		0.252			
	¼'' - 1''	.456	.226	1.868	.002		1.469			
	1'' - 3''	.092	.082	1.486	.001		3.142			
	Total	1.440	0.923	6.707	0.007	9.077	4.863	10.745	0.177	24.862
		(3.23)	(2.07)	(15.03)	(.02)	(20.30)	(10.90)	(24.10)	(.40)	(55.73)
2	Foliage	0.521	0.199	2.401	0.195					
	0'' - ¼''	.308	.118	2.064	.183		0.276			
	¼'' - 1''	.468	.138	2.532	.215		1.595			
	1'' - 3''	.091	.081	1.998	.227		3.681			
	Total	1.388	0.536	8.986	0.820	11.730	5.552	12.255	0.177	29.714
		(3.11)	(1.20)	(20.14)	(1.84)	(26.30)	(12.44)	(27.47)	(.40)	(66.61)
3	Foliage	0.942	0.865	1.626	0.002					
	0'' - ¼''	.564	.523	1.446	.002		0.351			
	¼'' - 1''	.874	.684	1.771	.001		1.480			
	1'' - 3''	.181	.477	1.565	—		3.344			
	Total	2.561	2.549	6.408	0.005	11.523	5.175	14.607	0.109	31.414
		(5.74)	(5.71)	(14.36)	(.01)	(3.41)	(11.60)	(32.74)	(.24)	(70.42)
4	Foliage	0.698	1.535	1.353	0.182					
	0'' - ¼''	.456	.964	1.210	.146		0.222			
	¼'' - 1''	.824	1.408	1.475	.173		1.083			
	1'' - 3''	.180	1.098	1.312	.085		2.502			
	Total	2.158	5.005	5.350	0.586	13.099	3.807	15.783	0.036	32.725
		(4.84)	(11.22)	(11.99)	(1.31)	(29.36)	(8.53)	(35.38)	(.08)	(73.36)

[1]Total weight by species from Gardner and Hann 1972; size classes estimated using Brown 1976.
[2]Material < 3-in diameter (7.6 cm); total weight from Hann 1972; size classes apportioned.
[3]From Gardner and Hann 1972, duff depths using specific gravity of 0.125.
[4]Schmidt and Lotan 1980.

Table 22.—Ground cover, fuel depth, and duff depth by unit, pre- and postharvest, first year[1]

Ground cover[2]	Unit 1		Unit 2		Unit 3		Unit 4	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post
	Percent							
Mineral soil	2	37	[3]	26	1	32	2	48
Rock	0	0	0	0	0	0	1	0
Needles	46	32	53	41	49	40	50	21
Wood	28	31	21	32	17	27	14	31
Moss	0	0	0	0		0	0	0
Grass	20	0	9	[3]	17	[3]	24	[3]
Brush	3	0	17	0	15	7	8	0
Total	100	100	100	100	100	100	100	100
Fuel depth, inches	21.4	2.1	14.6	7.4	12.7	7.4	10.3	3.6
(cm)	(54.3)	(3.3)	(5.3)	(18.8)	(32.2)	(18.8)	(26.2)	(9.1)
Duff depth,[4] inches	0.74	—	0.84	—	1.00	—	1.10	—
(cm)	(1.9)		(2.13)		(2.54)		(2.8)	

[1]Source: Resources Evaluation Work Unit, INT-Ogden (data on file, INT, Missoula).
[2]Items may not total 100 percent due to rounding.
[3]Less than 0.5 percent.
[4]Duff depth not measured postharvest.

Table 23.—Litter and duff depth and weight

	Fourth year postharvest[1]					Eighth year postharvest[2]	
	Litter & duff depth		Specific gravity	Kg/ha	Tons/acre	Duff and litter depth	
	cm	*Inches*	*g/cm*			*cm*	*Inches*
Undisturbed forest	2.6	1.02	0.13	35 494	15.83	0.9	0.35
Broadcast burn	1.8	.71	.17	34 995	15.61	not available	
Pile/burn							
Under piles	1.7	.67	.17	31 985	14.27	—	—
Between piles	1.3	.51	.23	33 222	14.82	1.2	.47
Residue-removed	2.4	.94	.20	42 213	18.83	2.2	.87
Chip-spread	11.7	4.61	.16	180 582	80.56	11.2	4.41

[1]Field data and compilations by N. DeByle, INT, Logan.
[2]Field measurements by R. Benson, INT, Missoula.

Table 24.—Understory vegetation, fifth year after harvest, by treatment and subunit

Undisturbed forest[1]		Treatment							
		Pile/burn		Broadcast burn		Residue-removed		Chip-spread	
Sample unit	kg/ha	Sub-unit	kg/ha	Sub-unit	kg/ha	Sub-unit	kg/ha	Sub-unit	kg/ha
1	397	2S	637	2S	244	4S	422	4E	190
2	397	2N	438	2N	439	4N	700	4W	98
3	244	3S	267	3S	373	1W	389	1W	70
4	82	3N	363	3N	311	1E	809	1E	72
Mean	280		427		342		580		107
(Lb/acre)	(249)		(380)		(305)		(517)		(95)

[1]Sample subunits. **Undisturbed:** 1, 2, 3, 4 in forest adjacent to respective units. **Treatment:** 2S = Unit 2 South; 3S = Unit 3 South, etc., in respective treatments.

Source: W. Schmidt 1980.

Table 25.—Concentrations of available nutrients in mineral soil in 1977

Depth and treatment	Available phosphorus	Extractable Potassium	Extractable Calcium	Extractable Magnesium	Available Boron	Available Zinc	Available Iron
	ppm	*Meq/100 g*			*ppm*		
0-5 cm:							
Forest	31.2	0.50	7.55	1.42	1.65	4.08	230
Broadcast burned	50.8	.58	9.95	1.98	1.58	7.12	206
Piled/burned, under	60.8	.68	14.60	2.05	1.62	12.25	302
Piled/burned, between	48.8	.50	7.18	1.62	1.05	4.45	219
Residue-removed	59.2	.58	8.80	1.82	1.82	3.88	241
Chip-spread	67.5	.55	8.22	1.72	1.78	4.08	446
5-15 cm:							
Forest	34.8	.42	4.68	0.98	0.85	1.55	256
Broadcast burned	49.2	.40	5.40	1.25	.65	2.20	266
Piled/burned, under	56.2	.60	6.78	1.62	1.50	4.95	305
Piled/burned, between	48.0	.40	5.72	1:25	1.22	7.32	280
Residue-removed	55.5	.45	6.02	1.35	.95	2.10	284
Chip-spread	62.2	.45	6.10	1.40	.90	2.60	445

Source: N. DeByle 1980.

Table 26.—Average concentrations of nutrients in soil solutions, 1977

Nutrient	Treatment: Forest	Broadcast burn	Pile/ burn (under)	Pile/ burn (between)	Residue-removed	Chip-spread
	mg/liter					
Nitrate-nitrogen	0.1	1.5	4.4	1.2	1.0	0.9
Potassium	.6	1.6	2.0	1.0	1.0	1.6
Calcium	2.6	5.3	11.9	4.2	4.2	6.8
Magnesium	.7	1.4	3.3	1.1	1.1	1.6
Sodium	1.4	1.1	2.2	1.0	2.0	1.2

Source: DeByle 1980.

Table 27.—Nutrients and ash in biomass per hectare of surviving 2-0 lodgepole pine, five growing seasons after planting

Treatment and tree component	N	P	K	Ca	Mg	Ash
	Grams/hectare					
Broadcast burned						
Needles	316	36	149	54	27	643
Wood, bark, buds	120	19	84	25	20	463
Roots	32	7	28	11	11	451
Total	**468**	**62**	**261**	**90**	**58**	**1 557**
Piled/burned						
Needles	388	38	147	88	30	850
Wood, bark, buds	170	28	113	32	28	644
Roots	39		9	33	101	1 476
Total	**597**	**75**	**293**	**130**	**69**	**1 970**
Residue-removed						
Needles	185	20	74	27	13	337
Wood, bark, buds	81	12	53	18	13	268
Roots	20	4	17	8	7	275
Total	**286**	**36**	**144**	**53**	**33**	**880**
Chip-spread						
Needles	83	10	35	11	6	152
Wood, bark, buds	36	6	24	6	5	105
Roots	13	3	9	4	4	141
Total	**132**	**19**	**68**	**21**	**15**	**398**

Source: DeByle 1980.

Table 28.—Volume and value of timber harvest, actual 1971 conditions (volumes per acre not adjusted)

	Conventional			Residue removed		
	Vol/acre[1]	\$/unit	\$/acre	Vol/acre[1]	\$/unit	\$/acre
Preharvest, ft^3/acre	10,175	—	—	9,675	—	—
Postharvest, ft^3/acre	3,567	—	—	729	—	—
Harvest costs						
Saw log, ft^3/acre	6,608			4,366		
M bd.ft./acre	23.2	[2]20.26	470	15.0	[2]20.64	310
Residues, ft^3/acre	0	0	0	4,580	[3].137	627
Total costs			470			937
Values						
Saw log, M bd.ft.	23.2	[4]55.71	1,292	15.0	[4]55.71	836
Chips, ft^3	0	0	0	4,580	[5].129	591
Net value of timber:						
with chips			822			480
without chips			822			– 101

[1]Gardner and Hann 1972.
[2]Stump to truck (hauling cost of \$12.90/M bd.ft. deducted); from Gardner and Hartsog 1973.
[3]Chip costs converted from 2,400 lb Bone Dry Unit (BDU) at rate of 96 ft^3 solid wood per unit. Costs stump to chipper = \$0.096/ft^3; through chipper = \$0.137/ft^3. (Hauling costs deducted.) From Gardner and Hartsog 1973.
[4]1971 values on truck \$55.71/M bd.ft., based on sales in area.
[5]Assumes chip values = \$0; or \$12.42/96 ft^3 BDU (1971 price at mill = \$21, less \$6.48 haul cost, less \$2.10 screen loss).

Table 29.—Cost of postharvest activities

	Actual cost 1971	Adjusted to 1980 dollars[1]
	Dollars per acre	
Broadcast burn		
Fireline	4.86	8.70
Burn (including overhead)	13.81	24.72
Planting	122.89	219.98
Seeding	75.33	134.84
Pile/burn		
Piling	35.71	63.92
Burn (including overhead)	7.70	13.78
Planting	133.48	238.93
Seeding	61.12	109.40
Residue-removed		
Planting	156.92	280.87
Seeding	66.93	119.80
Chip-spread		
Planting	146.00	261.34
Seeding	53.05	94.96
All areas		
Fencing	61.50	110.08
Rodent control	3.00	5.37

[1]Using GNP implicit price deflator, 1972 = 100:

$$\frac{1980 = 172}{1971 = 96} = 1.79 \text{ X } 1971 \text{ dollars} = 1980 \text{ dollars.}$$

Table 30.—Volume and value of timber harvest under assumptions of equal (adjusted) volume per acre and improved saw log recovery

	Conventional			Residue-removed		
	Volume/acre	$/unit	$/acre	Volume/acre	$/unit	$/acre
Preharvest, ft³/acre[1]	9,800	—	—	9,800	—	—
Postharvest[1]	3,435	—	—	738	—	—
Harvest costs						
Saw logs	[2]20	20.26	405	[2]20	20.64	413
Residue	0	0	0	2,877	.137	394
Total cost						
1971 dollars			405			807
1980 dollars[3]			725			1,444
Values						
Saw log	[2]20	55.71	1,114	[2]20	55.71	1,114
Residue	0	0	0	2,877	.129	371
Total value						
1971 dollars			1,114			1,485
1980 dollars[3]	1,994	2,658				
Net timber values:						
1971 dollars			709			678
1980 dollars[3]			1,269			1,214

[1]Assumed volume for both treatments equals 9,800 ft³/acre; postharvest residue components derived by adjusting table 28 (actual volume) up or down proportionately.

[2]Assumes saw log recovery improved to 20 M bd.ft. on residue-removed, and chip recovery adjusted accordingly.

[3]Using GNP implicit price deflator (1972 = 100): 1971 = 96, 1980 = 172; and therefore 1980 dollars = $\frac{172}{96}$ = 1.79 X 1971 dollars.

Table 31.—Stocking, average size, and volume of green trees at culmination of board foot MAI (assumes no substantial mortality between ages 5 and 20)

Treatment[2]	Average tree at culmination of board foot MAI: No./acre	Diameter	Height	Board foot	Top[3] (2-6 in)	Total[3] green residue
					Ft[3]	*Ft*[3]*/acre*
Pile/burn						
P	400	9.1	67	47	2.8	1,120
S	458	8.5	62	36	2.6	1,190
N	675	7.4	71	28	3.7	2,497
Broadcast burn						
P	400	9.1	67	47	2.7	1,080
S	400	9.1	67	47	2.7	1,080
N	198	12.1	77	117	2.0	396
Chip-spread						
P	225	11.6	77	104	2.1	472
S	176	12.4	74	119	1.8	317
N	157	13.1	77	146	1.8	283
Residue-removed						
P	249	11.2	76	94	2.2	548
S	400	9.1	67	47	2.8	1,120
N	532	8.1	67	34	3.5	1,862

[1]From table 14.
[2]See treatments, table 14.
[3]Developed from stand growth projections by D. M. Cole, INT, Bozeman.

Table 32.—Stocking, average size, and volume of green trees at culmination of board foot MAI (assumes 1.5 percent annual mortality between ages 5 and 20)

Treatment[2]	Average tree at culmination of board foot MAI: No./acre	Diameter	Height	Board foot	Top[3] (2-6 in)	Total[3] green residue
					Ft[3]	*Ft*[3]*/acre*
Pile/burn						
P	297	10.4	72	73	2.2	653
S	208	11.9	77	112	2.0	416
N	614	7.7	71	31	3.5	2,149
Broadcast burn						
P	313	10.2	72	69	2.2	689
S	249	11.2	76	94	2.1	522
N	176	12.4	75	121	1.9	334
Chip-spread						
P	194	12.0	73	109	1.9	369
S	107	14.6	76	192	1.4	150
N	137	13.5	75	154	1.6	219
Residue-removed						
P	198	12.1	77	117	2.0	396
S	151	13.1	75	142	1.7	256
N	505	8.3	68	37	3.4	1,717

[1]From table 14.
[2]See treatments, table 14.
[3]Developed from stand growth projections by D. M. Cole, INT, Bozeman.

Table 33a.—Projected live and dead tree stocking and dead tree volume, by treatment[1] (assumes no substantial mortality between ages 5 and 20)

Treatment[2]	Live trees/acre: At "4.6"[3] d.b.h.	Live trees/acre: At 100 years	Live trees/acre: At bd.ft. MAI	Dead trees at 100 years: No.[4]/acre	Dead trees at 100 years: D.b.h.[5]	Dead trees at 100 years: Height[5]	Dead trees at 100 years: Volume[5]/tree	Additional at MAI: No.[4]/acre	Additional at MAI: D.b.h.[5]	Additional at MAI: Height[5]	Additional at MAI: Volume[6]/tree	Total dead at 100 years	Additional at MAI	Total at MAI
							Ft^3				Ft^3			
PB/P	597	400	400	197	6	40	3.85	—	—	—	—	758	—	758
S	646	419	419	227	6	40	3.85	—	—	—	—	874	—	874
N	1,702	976	675	726	5	45	3.00	301	6	60	5.69	2,178	1,713	3,891
BB/P	597	400	400	197	7	45	5.80	—	—	—	—	1,143	—	1,143
S	597	400	400	197	7	45	5.80	—	—	—	—	1,143	—	1,143
N	299	228	198	71	8	50	8.30	30	10	65	16.43	589	493	1,082
CS/P	349	261	225	88	7	40	5.18	36	10	65	16.43	456	591	1,047
S	240	188	176	52	9	50	10.42	12	11	65	19.75	542	237	779
N	230	181	157	49	8	40	6.70	24	12	70	25.08	328	602	930
RR/P	399	291	249	108	7	45	5.80	42	9	60	12.42	626	522	1,148
S	597	400	400	197	7	45	5.80	—	—	—	—	1,143	—	1,143
N	1,001	588	532	413	5	35	2.38	56	7	60	7.65	983	428	1,411

[1]Developed from projections by D. M. Cole, INT, Bozeman.
[2]See treatment column, table 14.
[3]From projection: "4.6" is at a variable age.
[4]By subtraction using projection.
[5]Estimated from average size by decade.
[6]Computed from Faurot 1977.

Table 33b.—Projected live and dead tree stocking and dead tree volume, by treatment[1] (assumes no 1.5 percent annual mortality between ages 5 and 20)

Treatment[2]	Live trees/acre: At "4.6"[3] d.b.h.	Live trees/acre: At 100 years	Live trees/acre: At bd.ft. MAI	Dead trees at 100 years: No.[4]/ acre	Dead trees at 100 years: D.b.h.[5]	Dead trees at 100 years: Height[5]	Dead trees at 100 years: Volume[5]/ tree	Additional at MAI: No.[4]/ acre	Additional at MAI: D.b.h.[5]	Additional at MAI: Height[5]	Additional at MAI: Volume[6]/ tree	Total dead at 100 years	Additional at MAI	Total at MAI
							*Ft*³				*Ft*³			
PB/P	430	322	297	208	7	40	5.18	25	10.0	70	17.65	1,077	441	1,518
S	319	241	208	78	8	40	6.70	33	11.0	70	21.21	523	700	1,223
N	1,437	870	614	567	5	45	3.00	256	7.0	65	8.24	1,701	2,109	3,810
BB/P	488	340	313	148	6	35	3.45	27	10.0	70	17.65	511	476	987
S	399	291	249	108	6	35	3.45	42	10.0	70	17.65	373	741	1,114
N	240	188	176	52	7	35	4.54	12	12.0	70	25.08	241	301	542
CS/P	270	208	194	62	8	40	6.70	14	11.5	70	22.95	415	321	736
S	140	114	107	26	8	35	5.90	7	14.0	70	33.75	153	236	489
N	180	146	137	34	8	35	5.90	8	13.0	70	29.26	184	234	418
RR/P	299	228	198	71	7	35	4.54	30	11.0	75	22.45	322	673	995
S	200	161	151	39	8	40	6.70	10	12.0	75	26.85	261	268	529
N	919	557	505	362	6	40	3.85	52	8.0	65	10.70	3,873	525	4,398

[1]Developed from projections by D. M. Cole, INT, Bozeman.
[2]See treatment column, table 14.
[3]From projection: "4.6" is at a variable age.
[4]By subtraction using projection.
[5]Estimated from average size by decade.
[6]Computed from Faurot 1977.

Table 34.—Summary of saw log and residue volume at culmination of mean annual board foot increment

Treatment[1]	Saw log	Residues		
		Green	Dead	Total
	M bd.ft./acre	---------- *Ft³/acre* ----------		
Assumes no mortality between ages 5 and 20				
PB/P	18.7	1,120	758	1,878
S	16.6	1,190	874	2,064
N	19.0	2,497	3,891	6,388
BB/P	18.7	1,080	1,143	2,223
S	18.7	1,080	1,143	2,223
N	23.1	396	1,082	1,478
CS/P	23.3	472	1,047	1,519
S	21.0	317	779	1,096
N	22.9	283	930	1,213
RR/P	23.4	548	1,148	1,696
S	18.7	1,120	1,143	2,263
N	18.1	1,862	1,411	3,273
Assumes 1.5 percent annual mortality, ages 5 to 20				
PB/P	21.6	653	1,518	2,171
S	23.2	416	1,223	1,639
N	19.3	2,149	3,810	5,959
BB/P	21.6	689	987	1,676
S	23.4	522	1,114	1,636
N	21.3	334	542	876
CS/P	21.1	369	736	1,105
S	20.5	150	489	639
N	21.1	219	418	637
RR/P	23.1	396	995	1,391
S	21.4	256	529	785
N	18.7	1,717	4,398	6,115

[1]See treatments, table 14.

Table 35a.—Summary of expected timber values, based on projected volumes, and 1971 logging costs and values (in 1980 dollars) (assumes no substantial mortality between ages 5 and 20)

1971 treatment[1]	Projected future stand: Saw log only: Volume	Harvest cost[2]	Value[2]	Net	Residues (chipped): Volume	Harvest cost[2]	Value[3]	Net	Total net (saw log and chips)
	M bd.ft./acre	*$/acre*			*Ft³/acre*	*$/acre*			*$/acre*
PB/P	18.7	678	1,865	1,187	1,878	460	434	−26	1,161
S	16.6	602	1,655	1,053	2,064	506	477	−29	1,004
N	19.0	689	1,894	1,205	6,388	1,565	1,476	−89	1,116
BB/P	18.7	678	1,865	1,187	2,223	545	513	−32	1,155
S	18.7	678	1,865	1,187	2,223	545	513	−32	1,155
N	23.1	838	2,303	1,465	1,478	362	341	−21	1,444
CS/P	23.3	861	2,323	1,462	1,519	372	350	−22	1,440
S	21.0	776	2,094	1,318	1,096	268	253	−15	1,081
N	22.9	846	2,283	1,437	1,213	297	280	−17	1,196
RR/P	23.4	865	2,333	1,468	1,696	415	392	−23	1,445
S	18.7	691	1,865	1,174	2,263	554	523	−31	1,143
N	18.1	669	1,805	1,136	3,273	802	756	−46	1,090

[1]See treatments, table 14.
[2]At 1980 cost of $36.27/M bd.ft. in PB & BB; $36.95/M bd.ft. in CS & RR; $0.245/ft³ residues in all units.
[3]At 1980 values = 1.79 X 1971 values = $99.72/M bd.ft. saw logs and $0.231/ft³ for chips.

Table 35b.—Summary of expected timber values, based on projected volumes, and 1971 logging costs and values (in 1980 dollars) (assumes 1.5 percent annual mortality between ages 5 and 20)

1971 treatment[1]	Projected future stand: Saw log only: Volume	Harvest cost[2]	Value[2]	Net	Residues (chipped): Volume	Harvest cost[2]	Value[3]	Net	Total net (saw log and chips)
	M bd.ft./acre	*$/acre*			*Ft³/acre*	*$/acre*			*$/acre*
PB/P	21.6	783	2,153	1,371	2,171	532	501	−31	1,340
S	23.2	841	2,313	1,472	1,639	401	379	−22	1,450
N	19.3	700	1,924	1,225	5,959	1,460	1,376	−83	1,142
BB/P	21.6	783	2,154	1,371	1,676	410	387	−23	1,348
S	23.4	849	2,333	1,484	1,636	401	378	−23	1,461
N	21.3	772	2,124	1,352	876	215	202	−13	1,339
CS/P	21.1	780	2,104	1,324	1,105	271	255	−16	1,308
S	20.5	757	2,044	1,287	639	156	148	− 8	1,279
N	21.1	780	2,104	1,324	637	156	148	− 8	1,316
RR/P	23.1	853	2,303	1,450	1,291	341	321	−20	1,430
S	21.4	791	2,134	1,343	785	192	181	−11	1,332
N	18.7	691	1,865	1,174	6,115	1,498	1,412	−86	1,088

[1]See treatments, table 14.
[2]At 1980 cost of $36.27/M bd.ft. in PB & BB; $36.95/M bd.ft. in CS & RR; $0.245/ft³ residues in all units.
[3]At 1980 values = 1.79 X 1971 values = $99.72/M bd.ft. saw logs and $0.231/ft³ for chips.

Table 36.—Worksheet for deriving grazing values, by treatment

A. WEIGHT OF UNDERSTORY VEGETATION AVAILABLE[1] AND UTILIZABLE[2] ANNUALLY

Treatment	Period (years after harvest)					
	1-10		11-25		26-100	
	Production	Utilization	Production	Utilization	Production	Utilization
	Lb/acre					
Uncut	300	150	300	150	300	150
Residue-removed	None—No grazing allowed		650	325	300	150
Chip-spread	None—No grazing allowed		75	37	300	150
Pile/burn	None—No grazing allowed		700	350	300	150
Broadcast burn	None—No grazing allowed		800	400	300	150

B. AVERAGE ANNUAL WEIGHT OF UTILIZABLE VEGETATION OVER 100-YEAR PERIOD

Treatment	[1st 10 years X] +	[15 years X] +	[75 years X] [÷ 100 years] =	[average annual for 100-yr period]
Uncut	150	150	150	150
Residue-removed	0	325	150	161
Chip-spread	0	37	150	113
Pile/burn	0	350	150	165
Broadcast burn	0	400	150	172

C. AUM's[3] AND AVERAGE ANNUAL VALUE[4] FOR GRAZING, FOR PERIODS 11-25 YEARS, AND FOR 100 YEARS

Treatment	Grazing period 11-25 years only		Grazing for 100 years	
	AUM/acre/yr	Value/yr	AUM/acre/yr	Value/yr
Uncut	0.19	0.42	0.19	0.42
Residue-removed	.42	.94	.21	.47
Chip-spread	.05	.11	.14	.31
Pile/burn	.45	1.01	.21	.47
Broadcast burn	.51	1.15	.22	.49

[1]Derived from Basile projection, figure 20.
[2]Assumed: 50 percent of vegetation is available.
[3]Assumed: 2.6 pounds forage/cwt, for a 1,000-lb cow (AUM) = 26 lb/day, X 30 days = 780 lb/AUM.
[4]Assumed: $2.25/AUM (this is slightly higher than central-Montana and Wyoming fees for 1979).

Table 37.—Wildlife evaluation for various species, alternative harvest systems, lodgepole pine type, Teton National Forest
(Index: 0 = least favorable for species; 100 = most favorable for species)

		Year 1		Year 20		Year 100	
		Forage	Cover	Forage	Cover	Forage	Cover
Moose							
Uncut stand		90	100	80	100	70	100
Residue-removed	Natural regeneration	10	0	50	50	90	100
	Planted	10	0	50	70	90	100
Chip-spread	Natural regeneration	0	0	10	10	30	40
	Planted	0	0	10	50	30	100
Pile/burn	Natural regeneration	5	5	50	50	90	100
	Planted	5	5	50	70	90	100
Broadcast burn	Natural regeneration	5	5	50	50	90	100
	Planted	5	5	50	70	90	100
Elk							
Uncut stand		70	100	60	100	50	100
Residue-removed	Natural regeneration	10	0	100	50	90	100
	Planted	0	0	100	70	90	100
Chip-spread	Natural regeneration	0	0	10	10	40	50
	Planted	0	0	10	50	40	100
Pile/burn	Natural regeneration	5	0	100	50	90	100
	Planted	5	0	100	70	90	100
Broadcast burn	Natural regeneration	5	0	100	50	90	100
	Planted	5	0	100	70	90	100
Birds							
Residue-removed	Natural regeneration	10	0	50	70	90	100
	Planted	10	0	50	80	80	90
Chip-spread	Natural regeneration	0	0	10	40	30	50
	Planted	0	0	10	50	30	90
Pile/burn	Natural regeneration	10	30	80	70	90	100
	Planted	10	30	80	80	90	90
Broadcast burn	Natural regeneration	10	30	80	70	90	100
	Planted	10	30	90	80	90	90
Pocket gophers							
Uncut stand		30		30		40	
Residue-removed	Natural regeneration	10		100		60	
	Planted	10		80		50	
Chip-spread	Natural regeneration	0		10		20	
	Planted	0		5		10	
Pile/burn	Natural regeneration	10		100		60	
	Planted	10		80		50	
Broadcast burn	Natural regeneration	10		100		60	
	Planted	10		80		50	

Source: G. Gruell, Office Report, Teton National Forest, June 15, 1973.

Table 38.—Managers' esthetic evaluation for alternative harvest method first year after logging and projections for 10 and 20 years hence (Index number: 0 = low esthetic value; 100 = high esthetic value)

Activity viewpoint	Uncut stand	Pile/burn	Residue-removed	Chip-spread
First year				
Moving car	100	20	73	67
Hiking or horseback	100	10	71	65
Camping	100	15	73	67
Picture taking	100	10	71	65
From overlook	100	5	68	62
From aircraft	100	20	73	67
Recreation day use	100	5	71	65
Year 10				
Moving car	94	30	88	69
Hiking or horseback	88	20	83	67
Camping	90	25	88	69
Picture taking	85	20	83	67
From overlook	80	15	78	64
From aircraft	95	30	88	69
Recreation day use	80	15	78	67
Year 20				
Moving car	77	45	100	71
Hiking or horseback	70	35	100	69
Camping	72	40	100	71
Picture taking	70	35	100	69
From overlook	68	30	100	66
From aircraft	77	45	100	71
Recreation day use	68	30	100	69

Source: Derived from office report, "Wyoming Logging Residue Study—Esthetic and Recreation Evaluation," by Reed Stalder, USDA Forest Service, R-4, Ogden, Utah.

Benson, Robert E. Management consequences of alternative harvesting and residue treatment practices—lodgepole pine. Gen. Tech. Rep. INT-132. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1982. 58 p.

Logging residues in lodgepole pine were treated by four methods: broadcast burned, piled and burned, removed from site, and chipped and spread on site. Each treatment was regenerated by planted seedlings, direct seeding, and natural regeneration. Effects on soil, water, microsite, microorganisms, vegetative development, wildlife habitat, and visual qualities were observed during a 10-year period. Analyses were made of immediate and projected long-term costs and benefits for both dollar and nondollar resource values.

KEYWORDS: lodgepole pine, slash disposal, logging costs, utilization, regeneration, soil and water, microsite, visual quality, value index

The Intermountain Station, headquarted in Ogden, Utah, is one of eight regional experiment stations charged with providing scientific knowledge to help resource managers meet human needs and protect forest and range ecosystems.

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User's Guide to the Stand Prognosis Model

William R. Wykoff
Nicholas L. Crookston
Albert R. Stage

THE AUTHORS

WILLIAM R. WYKOFF is a research forester with the Station's quantitative analysis of forest management practices and resources for planning and control research work unit at Moscow, Idaho. Mr. Wykoff received his B.S. in forest management (1970) from the University of Minnesota, St. Paul, and his M.S. in forest management (1975) from Washington State University, Pullman. Since joining the Station in 1974, he has worked on the development of tree growth models and the implementation of these models into the Stand Prognosis system.

NICHOLAS L. CROOKSTON is a research associate, College of Forestry, Wildlife and Range Sciences, University of Idaho, Moscow. He is currently working on the Canada/U.S. Spruce Budworms Program-West under an Intergovernmental Personnel Act agreement between the Pacific Northwest Station and the University of Idaho. He received his B.S. in botany in 1973 from Weber State College and his M.S. in forest resources in 1977 from the University of Idaho. His principal professional activities have been to incorporate models of dynamics of the mountain pine beetle/lodgepole ecosystem, the Douglas-fir tussock moth/forest ecosystem, and the western spruce budworm/forest ecosystem into extensions to the Stand Prognosis system.

ALBERT R. STAGE is principal mensurationist at the Forestry Sciences Laboratory, Moscow, Idaho. His research has included studies of planning methods for forest management, forest inventory techniques, site evaluation, and methods for estimation of stand growth and yield incorporating pest effects. He is Project Leader of a research team studying the problems of developing decision-support systems for forest management in the Northern Rocky Mountains.

RESEARCH SUMMARY

The Inland Empire version of the Prognosis Model, a computer program designed to simulate the development of forest stands, is described. The Inland Empire version is calibrated for eleven tree species occurring on over 30 habitat types. The individual tree is the basic unit of projection and most combinations of species and age classes can be accommodated. Available thinning options allow considerable latitude for simulation of management strategies.

Prognosis Model input consists of a stand inventory, including a list of sample trees, and a set of specially formatted instructions that indicate the options selected. The output includes distributions of trees per acre, volume per acre, accretion, and mortality by diameter at breast height and by species and tree value class. In addition, selected sample trees are displayed over time along with parameters that describe general stand characteristics that might influence tree growth.

The Prognosis Model can be linked to models that predict pest outbreaks and the impacts of host-pest interactions. It can also be linked to models that predict production of other forest resources. The combined outputs provides a basis for multiresource planning.

Preparation of input, interpretation of output, and model formulation are described. Guidelines are given for potential uses and limitations.

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INTRODUCTION

Silviculturists planning the management of Northern Rocky Mountain forests have found the Prognosis Model for stand development (Stage 1973b) to be a useful tool for comparing different stand treatments. Since its introduction, the model has grown and evolved. Additional silvicultural treatments have been included in its scope; capability to evaluate damage to stands by several pests has been added; the geographic range for which it has been calibrated has been increased; the operating procedures have been simplified; and the information displayed about the future stand has been modified to improve economic analyses of the treatment effects.

Regional variants of the Prognosis Model have been calibrated for eastern Montana and central Idaho. These versions differ in the way that some submodels are constructed. With a few modest exceptions, however, all versions use the same input procedures and produce the same output tables. Our discussions of submodels are based on the performance of the Inland Empire version (released July 1981). This manual should serve most users as a reference for input preparation, output interpretation, and expected model behavior. Specifics on submodel structure and development are, or will be, documented elsewhere (Stage 1973b, 1975; Hamilton and Edwards 1976; Monserud 1980).

Yield Data for Forest Planning

Expectations of future stand growth and yield are the basis for investments in silviculture. Whether to retain a particular mix of tree species and sizes, to start a new stand, or to treat the existing stand with fertilizers or pesticides are choices that depend on the manager's comparisons of future stand growth in relation to the objectives for which the forest property is managed. No one choice of silvicultural treatments will be right for all objectives.

When production of timber is one of the objectives, growth predictions are the basis for estimating the yield of products that could be removed from the stand at varying times in the future. To be most useful for planning, yield forecasts comparing alternative silvicultural regimens should accurately represent the differences in expected yield among the alternatives. Accuracy of yield estimates for a single alternative is less critical than accurate comparisons of differences between alternatives because the planning process will be repeated at intervals that are short in comparison to the lifespan of most forest stands. A further consequence of this long lifespan is that a majority of the decisions to be made concerning the silviculture of a forest are choices concerning treatment of existing stands—with all their idiosyncracies that result from pest attacks, destructive climatic events, and past use.

In our opinion, the basis for management planning decisions should be yield estimates that include properly weighted average effects of all factors that influence the growth of stands. The Prognosis Model incorporates the average effect of factors such as insect and disease damage, variation in climate, and silvicultural activities to the extent that these factors are represented in the data to which the models were fitted. For the most part, the growth sample was selected independent of pest activity or treatment history, and the data were not screened to remove any specific effects. When management actions can be shown to modify the effects of particular factors, the Prognosis Model should be modified to explicitly represent those factors. The only management activity explicitly recognized by the current version of the Prognosis Model is stocking reduction. The model, however, can be linked to "extensions" that predict insect outbreaks, shrub development, and the establishment of regeneration stands (see section titled USING THE PROGNOSIS MODEL AS A COMPONENT IN A PLANNING SYSTEM).

Consequences for streamflow from the forest, for wildlife populations, and for pest populations that inhabit the forest, as well as the capability of the forest to yield timber or provide recreation—all depend on how the dominant vegetation changes and is changed. Unfortunately, yield forecasts have traditionally emphasized the merchantable harvest that might be obtained, either immediately or as a sequence of yields obtainable at intervals of time into the future. Volumes of merchantable timber have been the most common units of measure because timber products have usually been the primary reason for investment. As other uses for the forest become more important, however, growth forecasts need to be stated in more fundamental descriptions of the future forest stand. Too often, evaluation of trade-offs among conflicting activities or objectives for use of forest resources has been hampered by lack of sensitivity of the forecasts to the interactions among ecosystem components. One objective for development of the Stand Prognosis Model is to so characterize stand dynamics that the model will provide a sensitive basis for representing ecosystem interactions involving the tree species.

Design Criteria for Development of Prognosis Model

The nature of the Inland Empire forests and the complexity of their management have influenced the design of the Prognosis Model. Early logging in the Northern Rocky Mountains removed mostly the high value species—western white pine (*Pinus monticola*) and western larch (*Larix occidentalis*)—leaving irregular stands of the more tolerant grand fir (*Abies grandis*), western redcedar (*Thuja plicata*), and western hemlock (*Tsuga heterophylla*).

Later many stands were partially cut for special products, such as transmission poles of western red cedar and western larch. Diseases, such as blister-rust and pole-blight, selectively killed western white pine. Root rots infected many species, creating openings in stands. Insects (including mountain pine beetle on ponderosa pine [*Pinus ponderosa*], lodgepole pine [*Pinus contorta*], and western white pine, the Douglas-fir beetle, and the fir engraver) also were responsible for creating openings in stands. These influences resulted in forests in

which practically every stand is a unique mixture of species and age classes. Consequently, traditional mensurational parameters such as site index and stand age are either impossible to determine correctly or are inappropriate values for representing yields.

Recognizing the features that call for differing treatment calls for a high degree of silvicultural skill. Likewise, recording these features in the inventory process so that the consequences of the alternative treatments can be estimated, calls for close coordination between inventory methods and the process for developing forecasts of subsequent yields.

These circumstances led to the following criteria for constructing the Prognosis Model.

1. **Use existing inventory methods as sources of input and produce initial estimates of volume and growth that are consistent with estimates calculated with standard inventory compilation techniques**. This criterion ensures that the data obtained in detailed silvicultural examination procedures, as well as in nationwide forest inventories such as those conducted by Forest Resources Evaluation units, can be used to initiate prognoses. When the yields estimated by the model are used in harvest-scheduling, there will be no need to resolve troublesome differences between the inventory compilation of forest-wide volumes and growth and the initial values for the same statistics derived from the yield tables. Methods of growth prediction that ignore the detail obtained by modern stand examinations bury the diversity and problems that are keys to effective management. It is more critical to evaluate schemes for recouping the productivity of stands afflicted with white pine blister rust, spruce budworm, or larch casebearer, than to evaluate the relatively minor effects of stocking control on the distribution of increment. To evaluate such schemes, however, requires close coordination in inventory and growth methodology.

2. **Applicable in all timber types and stand conditions encountered in the inventory; growth predictions are consistent with growth rates measured in the inventory**. Effective allocation of management funds depends on correctly identifying stands where treatment would most nearly achieve the objectives of management. To properly identify these stands, we need projection methods that are consistent in their estimates across a wide variety of species types, age structures, and site conditions. For example, decisions to convert from one species type to another can be rational only if methods for estimating yield for each of the types are based on the same assumptions and are expressed in the same units. This feature also assures that each and every stand encountered in the inventory can be accommodated by the program without forcing stands into inappropriate species composition or age structure classes.

3. **Treat stands as the basic unit of management; growth projections are dependent on interactions between trees within stands**. A stand is defined as an area of forest bounded by discontinuities in cover characteristics that are visibie on aerial photographs at scales of approximately 1:15,840. The goal of stand delineation is to define a portion of the forest that can be treated by one silvicultural prescription and respond in a way that can be related to the characteristics of the stand. A stand is comprehensible to other specialists—pathologists, entomologists or any of the many special disciplines from whom we seek advice—and it is possible for these specialists to interpret our predicted forest in the light of their discipline.

4. **Incorporate growth of the current inventory into projections**. This criterion serves two applications. First, for analyses of individual stands, the samples of current increment localize the projections to allow for unique variations in site and environment that are not represented in the model parameters. The calibration procedures that use these increment data reduce the need for variables representing site index, site stockability, and age structure that are so difficult to define for the complex stands of the Inland Empire. Second, for forest-wide planning, the increment samples ensure consistency with inventory compilations of current annual increment and provide essential feedback of effects of past management planning. For example, consider an effect analogous to the "allowable cut effect"; the "error allowable cut effect." Suppose that when calculating the allowable cut, we use a yield estimate that is erroneously high. Then, the cut calculated for the coming planning

period will be too high. Conversely, a low yield estimate will lead to a lower cut than desired (Stage 1973a).

5. **Provide links to other biotic and hydrologic components of the ecosystem and to economic analysis procedures for selecting the most appropriate regimens of management.** By maintaining individual-tree resolution throughout the period of simulated time, estimates of future interactions between the stand and other components of the ecosystem can be based on as much detail as is available from inventories of the present situation. The tree species, however, are only part of the vegetation. Shrub and herbaceous species also compete with the conifers and may be valued in their own right for forage and shelter for wildlife. Therefore, we designed the Prognosis Model to provide linkages to submodels that predict understory development. An understory development submodel has been calibrated for the grand fir-cedar-hemlock ecosystems of northern Idaho. It provides sufficient detail about the total vegetation to facilitate estimates of effects on streamflow, quality of wildlife habitat, and forage production.

What Management Actions can be Represented?

Silvicultural treatments that can be evaluated include stocking control, regeneration methods, site preparation, and pest management.

THE BASE MODEL

Stocking control options can represent:

1. Thinning from above or below to a user-specified residual basal area per acre.
2. Thinning from above or below to a user-specified residual trees per acre.
3. Removal of a user-specified segment of the d.b.h. distribution.
4. Specific tree selection where cut or leave designations are entered on the input tree records.

The user can combine options to implement special thinning strategies and, in addition, can control the species composition of the stand to favor desirable trees.

EXTENSIONS AND USER SUPPLIED MODIFICATIONS

Management activities that are not explicitly included in the stocking control options are represented in two ways. One way uses extensions to the base model containing additional submodels. The other way modifies the submodels for diameter growth, height growth, and mortality.

To evaluate silvicultural treatments related to pest management, the Stand Prognosis Model must be linked to models that predict pest outbreak and development. Models for Douglas-fir tussock moth (Monserud and Crookston 1982) and mountain pine beetle (Crookston and others 1978) are currently available, and a western spruce budworm model is under development by the CANUSA program.[1]

Within the grand fir-cedar-hemlock ecosystem, it is possible to simulate the establishment of seedlings following regeneration treatments. This requires, however, that the Prognosis Model be linked to a submodel that predicts regeneration establishment (Stage and Ferguson 1982).

---

[1]CANUSA: The Canada/United States spruce budworms program cosponsored by the USDA Forest Service and the Canadian Department of Environment, Canadian Forest Service.

What Data are Required to Describe the Stand?

The model is designed to start with sample inventories of actual stands. To begin the projection, the model needs data on:

1. Inventory design used to measure the stand:
   a. Basal area factor for variable radius plots
   b. Fixed plot area
   c. Critical diameter when fixed plots are used to measure small trees and variable radius plots are used to measure large trees
   d. Number of inventory plots
   e. Number of non-stockable plots.
2. Site conditions:
   a. Slope
   b. Aspect
   c. Elevation
   d. Habitat type
   e. Location (nearest National Forest).
3. Characteristics of each tree measured in the inventory:
   a. Variables that must be recorded for all trees:
      i. Identification for plot on which the tree was measured
      ii. Species
      iii. Current d.b.h.
   b. Variables that may be subsampled or omitted:
      i. Number of trees represented by a record (when a single record is used to represent a class of trees)
      ii. Periodic diameter increment
      iii. Crown ratio
      iv. Tree height
      v. Periodic height increment for seedling and sapling-sized trees
      vi. Tree value class
      vii. Cut or leave designation (used when specific trees are selected for removal).

The model will work if given only a description of the inventory design and information on diameter, species, and plot identification for each inventoried tree. The other variables, however, serve to better describe unique site and tree characteristics and will improve the resolution of the projection.

Organization of the Model

Figure 1 illustrates the flow of information through the Prognosis Model. Although the diagram is at a low level of resolution, it does show the relationship between major phases of the program. In the sections that follow, these phases will serve as the background for describing input requirements, growth model behavior, and the interpretation of output.

A projection begins by reading the inventory records and the descriptions of selected management options. If periodic increment is measured on a sample of the tree records, the increment equations will be adjusted to reflect unique growth characteristics of the stand. The inventory is then compiled to produce tables that describe initial stand conditions. When this summary is complete, the first projection cycle begins.

Each projection cycle starts with the simulation of silvicultural actions that have been scheduled for the cycle. Next, periodic diameter increment, periodic height increment, periodic mortality rate, and change in crown ratio are computed for each tree record in the inventory. Then, the tree attributes are updated, tree volumes are calculated, and tables that summarize projected stand conditions are compiled.

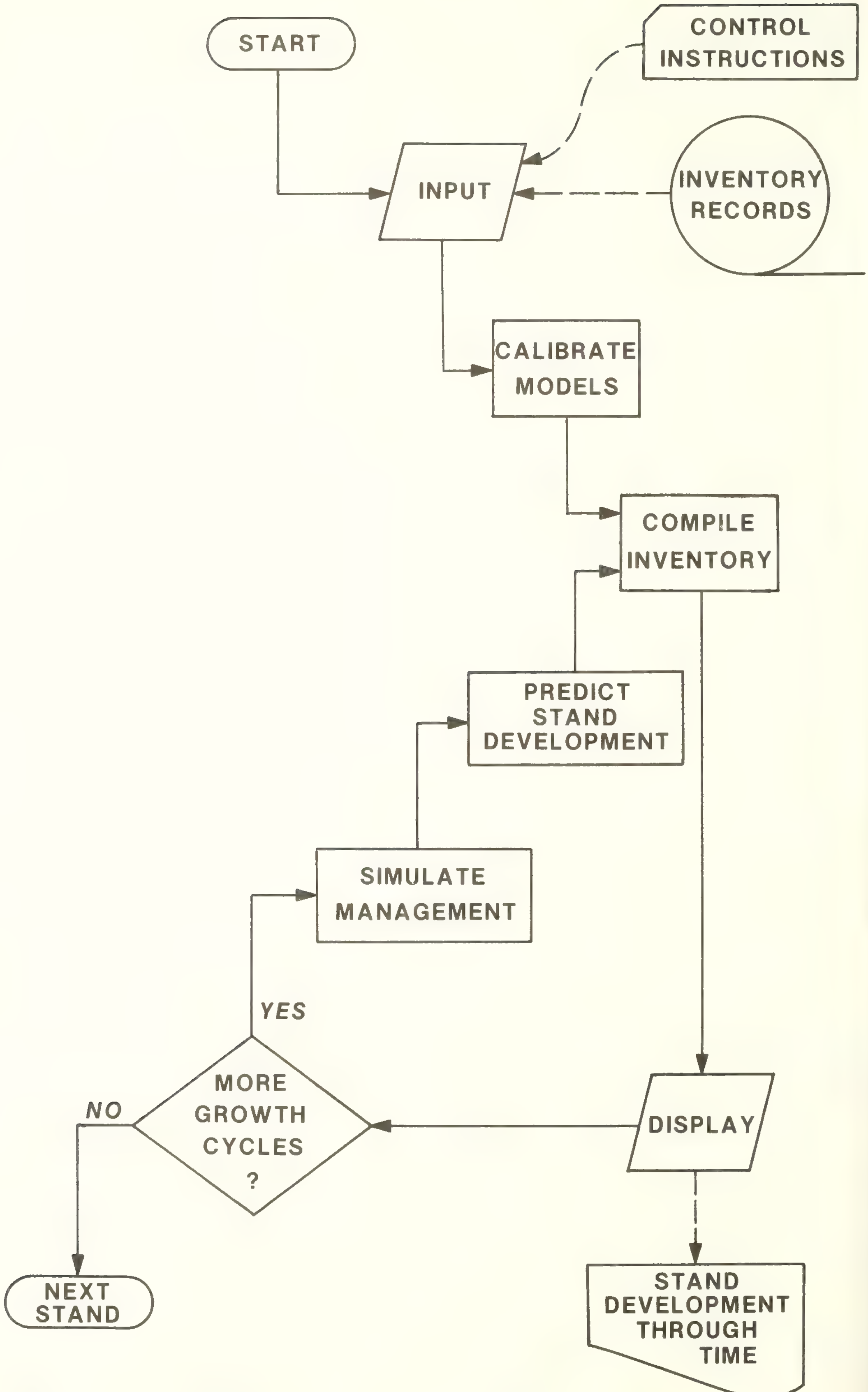


Figure 1.—A low resolution diagram showing the logical organization of the Prognosis Model.

The Keyword System

Users communicate much of the information used by the Prognosis Model through the keyword system. This system consists of a set of mnemonic words (keywords) associated with numeric data. A single keyword and its associated numeric data make up a keyword record. For example, the STDINFO record is the keyword record used to enter information about the site on which the stand is located.

The keyword always begins in the first column of the keyword record. Depending on the keyword, seven additional fields on the record may be used to transmit numeric data. These fields are referred to as parameter fields and the data are used by the program when the option is implemented. Each parameter field consists of 10 columns and, if the decimal point is included, the parameter may be entered anywhere within the field. If integer values are used, they must be right-justified. The first parameter field begins in column 11 on the keyword record (fig. 2).

```
                                     COLUMNS
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
--------------------------------------------------------------------------------

STDIDENT
S248112   HYPOTHETICAL PRESCRIPTION FOR USER'S MANUAL -- NIG4 VERSION
COMMENT
  THE PRESCRIPTION CALLS FOR IMMEDIATE REMOVAL OF
  EXCESS TREES, A COMMERCIAL THINNING AT AGE 90
  TO REMOVE LODGEPOLE AND LARCH, A SHELTERWOOD
  REGENERATION TREATMENT AT AGE 120 FAVORING
  GRAND FIR AND DOUGLAS-FIR, AND AN OVERWOOD
  REMOVAL AT AGE 130.
END
DESIGN                                            11.0      1.0
STDINFO         18.0     570.0      57.0           8.0      3.0      34.0
INVYEAR       1977.0
NUMCYCLE         8.0
THINPRSC      1980.0     0.999
SPECPREF      2010.0       2.0     999.0
SPECPREF      2010.0       7.0    9999.0
THINBTA       2010.0     157.0
SPECPREF      2040.0       3.0    -999.0
SPECPREF      2040.0       4.0     -99.0
THINBTA       2040.0      35.0
TREEDATA
PROCESS
STOP
```

Figure 2.—Examples of keyword records. This set of records was used to simulate a prescription that is developed later in the manual. Shown are keyword records, with keywords (columns 1 to 10) and parameters (10-column fields starting in column 11), and supplemental data records.

A simplifying feature of the keyword system is that default values exist for almost all program options. Keywords need only be used if the desired action differs from the default action. Similarly, most parameters associated with keywords have default values. If a parameter field is blank, the default value will be used. Returning to our earlier example, field 1 on the STDINFO record is used to specify the National Forest in which the stand is located. The default for this parameter is 18, the code used to represent the St. Joe National Forest. If the stand is located in the St. Joe, the first parameter field on the STDINFO record can be left blank.

The final element of the keyword system is the supplemental data record. These records are required when the information needed to implement an option is nonnumeric or exceeds seven values. The exact format of the supplemental data records is dependent on the option selected and will be described on a case-by-case basis.

We will introduce keywords in the course of describing how the Prognosis Model works and, as the keywords are presented, their function will be defined. For convenience, appendix D contains an index to the pages on which definitions of keywords are given and a summary of default conditions.

The Prognosis Model is primarily a tool for evaluating the biological consequences of silvicultural manipulation. When the model is used in this mode, three types of input are required. First, some simple keyword records are used to start and stop program execution and to specify the number and length of projection cycles. Another set of keywords is used to describe the stand and the sampling design. A final set of keywords controls simulation of various stand management options.

The minimum input required to run the Prognosis Model is a list of sample tree records, which are coded in accordance with the default tree record format, and a PROCESS record. The function of PROCESS is simply to terminate the input of the selected options. When PROCESS is encountered, the sample tree records are read and the projection begins.

PROCESS is the logical end of the collection of keyword records that define a single projection. Many projections may be grouped into a keyword record file. In this case, PROCESS serves to separate the projections. Each projection is completed before the keyword records for the next projection are read.

If the record following PROCESS is anything other than an end-of-file or a STOP, the default parameter values are recalled in preparation for the next projection. The STOP record is the logical end of the keyword record file. When STOP is encountered, program execution ends. In reality, STOP functions the same as an end-of-file. It serves as a visual reminder of the extent of the keyword file and a warning message is printed if STOP is not found.

Timing

A cycle is a period of time for which increments of tree characteristics are predicted. All management activities are assumed to take place at the beginning of the cycle in which they are scheduled. An inventory report is prepared at the end of each cycle. The number of cycles and the length of each cycle are controlled by using the NUMCYCLE and TIMEINT records.

NUMCYCLE	field 1:	The number of cycles that the stand is to be projected; default = 1.
TIMEINT	field 1:	Cycle number for which the cycle length is to be changed. If blank, the change will apply to all cycles.
	field 2:	The number of years to be projected in the cycle(s) referenced in field 1; default = 10 years.

An additional keyword record is needed so that options that are requested by date (as opposed to cycle) can be associated with projection cycles. This record is used to enter the starting date for the projection. The date entered is assumed to be the date that the stand was inventoried:

INVYEAR	field 1:	Starting date for the stand projection; default = 0.

Any starting date may be used. Care must be taken to assure that the dates on which options are requested fall within the range of dates defined by the parameters on the NUMCYCLE, TIMEINT, and INVYEAR records.

In the following example, we assume an inventory year of 1973, and we project to the year 2020, using a 7-year first cycle to align projection reports with decades. Subsequent cycles will all be 10 years long.

```
NUMCYCLE        5.0
TIMEINT         1.0          7.0
INVYEAR      1973.0
PROCESS
STOP
```

We use cycles to define the input parameters that relate to the growth models in order to emphasize that the models predict periodic increments. Most of the models are based on either 5- or 10-year increment data and we feel that, in most cases, a 10-year period should be used. There are legitimate reasons, as in the above example, for using other period lengths. Some bias is associated with using period lengths other than 10 years (table 1), however, and the choice of a different period length should be a deliberate decision.

Table 1.— Examples of biases in predicted stand attributes as related to period length for a 40-year projection. Stand A is an all-aged stand composed of 11 species with initial DBH's ranging from 0.1 to 35 inches (quadratic mean *DBH* = 7.0 inches). Stand B is a young, more or less even-aged stand, composed of 6 species with initial *DBH's* ranging from 4.0 to 12.7 inches (quadratic mean *DBH* = 7.2 inches)

Cycle length	Total volume	Bias[1]	Volume to 8 in top	Bias[1]	Trees per acre	Bias[1]
Years	*Ft*^{3}	*Percent*	*Bd.ft.*	*Percent*		*Percent*
			Stand A			
10	6,415	—	26,784	—	280	—
1	5,913	−7.8	25,655	−4.2	294	5.0
2	6,026	−6.1	25,678	−4.1	291	3.9
4	6,136	−4.4	25,528	−4.7	286	2.1
8	6,304	−1.7	26,254	−2.0	281	.4
20	7,377	15.0	32,527	21.4	284	1.4
40	16,368	155.2	82,609	208.4	280	.0
			Stand B			
10	5,829	—	23,940	—	221	—
1	6,054	3.9	25,940	5.8	219	−0.9
2	5,897	1.2	24,281	1.4	220	−.5
4	5,892	1.1	23,992	.2	221	.0
8	5,827	.0	23,836	−.4	221	.0
20	6,457	10.8	27,839	16.3	216	−2.3
40	8,385	43.8	38,941	62.7	190	−14.0

[1]Bias computed relative to prediction for 10-year projection cycles.

Entering Stand and Tree Data

The Prognosis Model is an inventory-based projection system that will accomodate a variety of sampling designs, site characteristics, and stand structures. These features are entered using seven keyword records. One record defines the parameters of the sampling design. Another record enters site characteristics such as slope, aspect, elevation, and habitat type. Four records provide control for reading the sample tree records. One record enters report labels. These records are described below.

THE SAMPLING DESIGN

The Prognosis Model will accommodate most sampling designs in which stands are delineated and individual sample trees within stands are selected with known probability. Acceptable designs include, but are not limited to:

1. One or more fixed area plots per stand.
2. One or more sample points **within a stand** where sample trees are selected using the **same** horizontal angle gauge.
3. Combinations where trees smaller than a specified diameter (*BRK*) are sampled using fixed area plots, and trees with diameter greater than or equal to *BRK* are sampled using a horizontal angle gauge (Stage and Alley 1972).

If other designs are used, preprocessing may be required to assign sampling probabilities to the individual tree records prior to submitting the stand for projection. In general, the sampling design that is most efficient for representing a given stand structure will provide the most effective input data for the Prognosis Model.

To enter information about the sampling design, you must use the DESIGN record:

DESIGN

field 1: basal area factor for horizontal angle gauge, default = 40 (square feet/tree).

field 2: Inverse of fixed plot area, default = 300 (acre^{-1}).

field 3: *BRK*, default = 5 (inches).

field 4: Number of plots in the stand. If blank, or zero, the number of plots in the stand is determined by counting the numbers of unique plot identification codes on the tree records.

field 5: Number of nonstockable plots in the stand. These include plots falling on rock outcroppings, roads, streams, etc. If blank, count nonstockable plots on tree records (*IMC* = 8; see discussion of tree records).

field 6: Sampling weight for stand. This weight does not affect the projection but is for use in programs that aggregate many projections to produce a composite yield table; default = number of plots.

Throughout this manual, a stand from the St. Joe National Forest (S248112)[2] is used to develop examples. This stand was inventoried using a combination of fixed and variable

[2]The stand number can be interpreted as follows: district (working circle) 2; compartment 48; subcompartment 1; stand 12.

plots as described above. Default values were used for basal area factor, *BRK*, and the inverse of the fixed plot area. There were 10 sample plots within the stand, and all were stockable. In this case, either of the following DESIGN records is correct:

DESIGN	40.0	300.0	5.0	10.0	0.0	b̸[3]

or

DESIGN	b̸	b̸	b̸	10.0	0.0	b̸

If a fixed-area-plot sampling design was used, simply specify a value of *BRK* that exceeds the diameter of the largest sample tree selected. For example, if 10 plots of 1/20-acre size were used, the DESIGN record could read:

DESIGN	b̸	20.0	99.0	10.0	0.0	b̸

If, however, all sample trees were selected using 10 points and a horizontal angle gauge (basal area factor = 40), the value of *BRK* should be set to zero:

DESIGN	40.0	b̸	0.0	10.0	0.0	b̸

IDENTIFYING THE STAND

The STDIDENT keyword record allows you to label output tables. None of the parameter fields are used, but one supplemental data record is required. This record contains a stand identification (such as S248112) in columns 1-8. This ID appears with every output table. Columns 9-80 can be used to transmit a "title" which will be reproduced at the beginning of each output table. The records

```
STDIDENT
S248112         STAND PROGNOSIS MODEL USER'S MANUAL EXAMPLE
```

identify the stand used and provide a title for the output.

In addition to a stand identification, you may enter a special code to identify the silvicultural treatment or management regimen that is simulated in a projection. The code is entered with the MGMTID record. There are no associated parameters, but the code to be used is entered in the first four columns of a supplemental record. When the supplemental record is blank, the code is not printed; when MGMTID is not used, the code "NONE" is printed. For example, the records

```
MGMTID
RUN1
```

would cause the label RUN1 to be printed with each output table.

DESCRIBING THE STAND

Many of the growth prediction equations in the Prognosis Model use stand variables such as habitat type, slope, aspect, elevation, and location. We assume that the stand is delineated so that these variables are reasonably constant. Stretching this assumption when defining stands, will increase the likelihood that projections will not be accurate. In particular, aspect is a circular function and habitat type and location are represented by discrete classes; none of these have meaningful averages.

[3]The symbol "b̸" is used here and elsewhere to indicate a blank field. We have made no attempt to maintain accurate spacing in our keyword examples. Instead, an entry is provided for each field.

The STDINFO record is used to supply data on stand variables:

STDINFO field 1: Forest code (see table 2). Forest code is used as the indicator of location for growth predictions; default = 18 (St. Joe NF).

field 2: Numeric habitat type code (see table 3); default = 260 (*Pseudotsugsa menziesii/Physocarpus malvaceus*).

field 3: Stand age in years. Age is used to label output and has no effect on tree growth predictions; it is required for some extensions; default = 0.

field 4: Aspect code: 1 = north, 2 = northeast, ..., 8 = northwest, 9 = level; default = 9.

field 5: Stand slope code: 0 = ≤ 5%, 1 = 6-15%, 2 = 16-25%,..., 9 = ≥ 86%; default = 0.

field 6: Stand elevation in 100's of feet. Example: 10 = 1000 ft, 35 = 3,500 ft; default = 38.

field 7: Site index. This value is used only to label the output. At present, none of the growth or mortality predictions depend on site index. Any numeric value may be entered; default = 0.

Valid forest and habitat type codes are listed in tables 2 and 3, respectively. If the stand in question is outside the boundaries of a National Forest, select the code associated with the nearest forest. If an invalid code is given, the default value (18) will be used. If invalid aspect or slope codes are encountered, the default values (9 and 0, respectively) will be used. Invalid elevation codes are not readily detected, however, and all entries are assumed to be correct.

Table 2.— Codes for the Forests represented in the Inland Empire version of the Prognosis Model

Forest	Code	Forest	Code
Bitterroot	3	Kaniksu	13
Clearwater	5	Kootenai	14
Coeur d'Alene	6	Lolo	16
Colville	7	Nezperce	17
Flathead	10	St. Joe	18

Table 3.— Codes for habitat types represented in the Inland Empire version of the Prognosis Model[1]

Code[2]	Abbreviation	Habitat type name
130	PIPO/AGSP	*Pinus ponderosa/Agropyron spicatum*
170	PIPO/SYAL	*Pinus ponderosa/Symphoricarpos albus*
250	PSME/VACA	*Pseudotsuga menziesii/Vaccinium caespitosum*
260	PSME/PHMA	*Pseudotsuga menziesii/Physocarpus malvaceus*
280	PSME/VAGL	*Pseudotsuga menziesii/Vaccinium globulare*
290	PSME/LIBO	*Pseudotsuga menziesii/Linnaea borealis*
310	PSME/SYAL	*Pseudotsuga menziesii/Symphoricarpos albus*
320	PSME/CARU	*Pseudotsuga menziesii/Calamagrostis rubescens*
330	PSME/CAGE	*Pseudotsuga menziesii/Carex geyeri*
420	PICEA/CLUN	*Picea/Clintonia uniflorum*
470	PICEA/LIBO	*Picea/Linnaea borealis*
510	ABGR/XETE	*Abies grandis/Xerophyllum tenax*
520	ABGR/CLUN	*Abies grandis/Clintonia uniflorum*
530	THPL/CLUN	*Thuja plicata/Clintonia uniflorum*
540	THPL/ATFI	*Thuja plicata/Athyrium filix-femina*
550	THPL/OPHO	*Thuja plicata/Oplopanax horridum*
570	TSHE/CLUN	*Tsuga heterophylla/Clintonia uniflorum*
610	ABLA/OPHO	*Abies lasiocarpa/Oplopanax horridum*
620	ABLA/CLUN	*Abies lasiocarpa/Clintonia uniflorum*
640	ABLA/VACA	*Abies lasiocarpa/Vaccinium caespitosum*
660	ABLA/LIBO	*Abies lasiocarpa/Linnaea borealis*
670	ABLA/MEFE	*Abies lasiocarpa/Menziesia ferruginea*
680	TSME/MEFE	*Tsuga mertensiana/Menziesia ferruginea*
690	ABLA/XETE	*Abies lasiocarpa/Xerophyllum tenax*
710	TSME/XETE	*Tsuga mertensiana/Xerophyllum tenax*
720	ABLA/VAGL	*Abies lasiocarpa/Vaccinium globulare*
730	ABLA/VASC	*Abies lasiocarpa/Vaccinium scoparium*
830	ABLA/LUHI	*Abies lasiocarpa/Luzula hitchcockii*
850	PIAL-ABLA	*Pinus albicaulis-Abies lasiocarpa*
999	OTHER	

[1]From Pfister and others 1977.
[2]The codes given are for habitat types. Phases are treated as subsets of habitat types. For instance, the codes 261 and 262 are interpreted the same as code 260.

Our example stand, S248112, is located in the St. Joe National Forest (code 18). This stand is on a northwest-facing slope of approximately 30 percent (aspect code = 8, slope code = 3) at 3400 feet elevation (code = 34). The habitat type has been identified as *Tsuga heterophylla/Clintonia uniflorum* (code = 570). This stand was inventoried in 1977, at which time its average age was 57 years. Site index is unknown. The above data could be entered into the Prognosis Model using the following keyword and supplemental data records:

```
STDIDENT
S248112        HYPOTHETICAL   PRESCRIPTION   FOR   USER'S   MANUAL
STDINFO         18.0     570.0     57.0     8.0     3.0     34.0   b̸
INVYEAR       1977.0
```

SAMPLE TREE DATA

The sample tree records (fig. 3) are another important component of the Prognosis Model input. The model predicts future tree heights and diameters from initial stand and tree characteristics and estimates of periodic increment. Stand data were described above. There are 13 variables used to describe trees and these are entered on the tree

```
                              COLUMNS
         1         2         3         4         5         6         7
1234567890123456789012345678901234567890123456789012345678901234567890
======================================================================
    S
     T            P
  R   A            L
   E   N            O                  I
    C   D            T   P           I P
     O                    R I I D    I  D IR     H T
      R    I        I      O T S B D  H C  C MS    T H
       D    D        D      B H P H G  T R  D CC    G T
      --  ------    ----   -----------  ----  ----   == ==
      1  248112     0101   011LP 11510  0734  0011    0  0
      2  248112     0102   011WH 06523  0308  0011    0  0
      3  248112     0102   031DF 001    0026  0022    0  0
      4  248112     0102   011L  07906  0753  0011    0  0
      5  248112     0102   016L  346          1032    0  0
      6  248112     0103   011L  08007  0633  7322    0 56
      7  248112     0103   011GF 06220  0385  0011    0  0
      8  248112     0103   011L  084      54  0011    0  0
      9  248112     0103   011LP 09511  0603  0011    0  0
     10  248112     0104   011DF 040    0203  0011   50  0
     11  248112     0104   011L  08212  0655  5011    0  0
     12  248112     0105   011DF 012    0116  0022   42  0
     13  248112     0105   011DF 019    0135  0022   47  0
     14  248112     0105   015LP 072          1132    0  0
     15  248112     0105   011C  001    0027  0022    0  0
     16  248112     0105   011GF 05309  0277  0011    0  0
     17  248112     0106   011DF 10010  0654  0011    0  0
     18  248112     0106   011GF 06112  0388  0011    0  0
     19  248112     0106   011DF 12716  0674  0011    0  0
     20  248112     0107                        80
     21  248112     0108   011LP 09605  0603  0022    0  0
     22  248112     0108   011DF 10409  0555  7422    0 49
     23  248112     0108   011LP 085      03  0011    0  0
     24  248112     0109   011GF 10910  0657  0011    0  0
     25  248112     0109   011DF 09418  0604  0011    0  0
     26  248112     0110   011C  03206  0175  0022   32  0
     27  248112     0110   031GF 001    0037  0022    0  0
     28  248112     0110   011C  05810  0287  0011    0  0
     29  248112     0110   011C  05010  0253  0011    0  0
     30  248112     0111   011GF 06614  0307  0011    0  0
```

Figure 3.—Sample tree records from the inventory of stand S248112 in the St. Joe National Forest.

records. Following is a description of what the variables are, how they should be coded, and how they are used in the Prognosis Model. Some variables may be omitted or subsampled. In these cases, zeroes and blanks are treated as missing values.

Plot ID (*ITRE*).—Each stand inventory consists of 1 or more inventory plots. The term "plot" is used to describe a fixed area plot, a variable radius plot, or the combination of the two when used to measure separate components of the stand (see the discussion of DESIGN). A unique **numeric** code should be assigned to each plot within a stand, and the code should be recorded on each record for a tree sampled on the plot. The plot ID's are used to determine the number of plots in the stand when a plot count is not provided on the DESIGN record.

Number of trees represented by a record (*PROB*).—Trees on a plot that are similar (classed together) may be recorded on a single record. When this option is used, the number of trees in a class must be recorded (see fig. 3, records 3 and 27). If *PROB* is not recorded, the record is assumed to represent a single sample tree.

Tree history (*ITH*).—Only the codes 5, 6, 7, and 9 are significant to the Prognosis Model. These codes indicate types of tree records that are **not projected**. All other codes are assumed to represent live trees, and they are projected. The code 5 trees (record number 14 in fig. 3) are assumed to have died during the mortality observation period (see the discussion of GROWTH). These records are used to backdate stand density statistics to the beginning of the growth measurement period for the purpose of increment model calibration. The codes 6 and 7 represent trees that have been dead for longer periods of time and records with these codes are ignored (see fig. 3, record 5).

The code 9 is used to indicate a special type of record (that is, a planar intercept record in the Forest Service's Region 1 inventory system; USDA Forest Service 1978) and the code 9 records are also ignored.

Species (*ISP*).—Species is used in the Prognosis Model to index the various growth models and categorize summaries. The species recognized by the Prognosis Model and the default codes for these species are shown in table 4. The default codes may be replaced using the SPCODES records as discussed in the section on species codes. All tree records with unrecognizable codes are treated as mountain hemlock (*Tsuga mertensiana*). The order in which the codes appear in table 4 (numeric codes) is the order in which species are subscripted within the Prognosis Model. Several keywords that relate to silviculture and growth model modification use species code in a parameter field. In these cases, the numeric species code must be used.

Table 4.—Tree species recognized by the Prognosis Model with Default coding conventions

Common name	Scientific name	Default input code	Numeric code
Western white pine	*Pinus monticola*	WP	1
Western larch	*Larix occidentalis*	L	2
Douglas-fir	*Pseudotsuga menziesii*	DF	3
Grand fir	*Abies grandis*	GF	4
Western hemlock	*Tsuga heterophylla*	WH	5
Western redcedar	*Thuja plicata*	C	6
Lodgepole pine	*Pinus contorta*	LP	7
Engelmann spruce	*Picea engelmannii*	S	8
Subalpine fir	*Abies lasiocarpa*	AF	9
Ponderosa pine	*Pinus ponderosa*	PP	10
Mountain hemlock	*Tsuga mertensiana*		11

Tree diameter breast height (*DBH*; measured in inches).—Most of the models which predict changes in tree attributes are dependent on *DBH*. Trees smaller than 4.5 feet in height should be assigned a small, but nonzero, diameter (for example 0.1 inch; see fig. 3, records 3, 15, and 27). This diameter will not be incremented unless projected height is greater than 4.5 feet. *DBH* must be recorded if the tree is to be projected; **records with blank or zero *DBH* values are ignored.**

Periodic diameter increment (*DG*; measured in inches).—Periodic diameter increment data is used to calibrate the diameter increment model. If *DG* is measured on two or more sample trees of a species, the model for that species is calibrated. Diameter increment data may be entered into the Prognosis Model in two ways: (1) a past or future outside bark *DBH* measurement; or (2) a past or future inside bark diameter increment measurement. If the first method is used, the program will automatically convert *DG* to an inside bark increment prior to calibration.

We recommend subsampling for diameter increment, with the sample trees selected in proportion to *DBH* squared or *DBH* cubed (Stage 1960).

We also recommend using a 10-year period to measure growth because the diameter increment model is based on data for a 10-year period. The form of the diameter increment model was selected in part to enhance extrapolation to different period lengths. However, this capability should not be abused without evaluating the biases. In general, period lengths ranging from 5 to 15 years are safe. Both the method of growth measurement and the length of the period are entered on the GROWTH keyword record, which will be described shortly.

Tree height (*HT*; measured in feet).—Tree height is the second most important tree attribute that is projected. Height is used in the height increment and crown ratio calculations and in the volume formulae. Heights may be omitted from the tree records or they may be subsampled. If omitted, initial heights will be calculated using species-specific height-diameter relationships that are imbedded in the program. If height is subsampled, and four or more trees of a species have recorded heights and no apparent top damage, the parameters of the height-diameter equation will be estimated from the input data.

When the top of the tree is missing or dead (damage code 73 or 74; see the damage code description in this section), the variable *HT* should be used to record the actual live height of the tree. This is the height that will be projected and used in growth predictions. Trees with top damage are not included in the height-diameter curve parameter estimates.

Two additional variables are needed to approximate a taper curve so that volume loss due to top-kill can be estimated (Monserud 1980). These are the estimated height if the tree were not top-killed (*NORMHT*) and the height to point of top-kill (*THT*). *NORMHT* is initially computed from the height-diameter function and is adjusted each cycle by adding the predicted height increment.

Height to point of top-kill (*THT*; measured in feet).—When the top is dead or missing, the height to point of top-kill should be recorded (see fig. 3, records 6 and 22). *THT* serves as a permanent point of truncation for volume calculations and is not incremented.

When the damage code indicates a dead or missing top, and *THT* is not recorded, the height to the point of top-kill is assumed to be 80 percent of *NORMHT* (the tree height estimated from the height-diameter function). If *HT* is not recorded, it is set equal to *THT*, regardless of whether *THT* was recorded or computed. In any case, the heights are constrained such that

$$THT \leq HT \leq NORMHT.$$

We recommend recording both *HT* and *THT* for trees with visible top damage.

Periodic height increment (*HTG*; measured in feet).—Height increment is used to calibrate the small-tree height increment model in the same way that diameter increment is used to calibrate the diameter increment model. *HTG* may be subsampled, and trees selected should have a *DBH* that is less than 5 inches (see fig. 3, records 10, 12, 13, and 26). *HTG* is entered into the Prognosis Model either by recording an increment (future or past) or a height (future or past). If heights are recorded, *HTG* will be automatically converted to an increment prior to calibration.

We recommend a 5-year period for measuring height increment because this is the period length on which our models were based. For periods longer than 5 years, it becomes increasingly difficult to measure increment without destructively sampling trees or using permanent sample plots. Both the method by which increment is measured and the period length are specified on the GROWTH keyword record.

Crown ratio code (*ICR*).—The ratio of live crown length to total height is an important predictor of diameter increment. *ICR* is coded into 10 percent classes (1 = 0-10 percent, 2 = 11-20 percent,..., 9 = > 80 percent). Within the program, *ICR* is converted to crown ratio (*CR*) by giving *CR* a value equal to the class midpoint. When *ICR* is missing, a value is computed using an imbedded equation. This equation is not calibrated from the input data.

Damage code (*IDCD*).—There are only two damage codes that are currently used by the Prognosis Model. If *IDCD* is equal to 73, the top is assumed to be dead; if *IDCD* is equal to 74 (see fig. 3, records 6 and 22), the top is assumed to be missing. These codes should be used in conjunction with actual and estimated tree heights as earlier described.

Tree value class code (*IMC*).—The tree value class is a factor in the formula which computes priority for removal if you specify thinnings. Four classes are allowed (codes 1,2,3,

and 8), and all other codes will be converted to 3. With all other factors held constant, code 3 trees will be removed prior to code 2 trees, and code 2 trees will be removed prior to code 1 trees.

Code 8 is used to include a null-record for a point that is nonstockable (see fig. 3, record 20). Once the nonstockable point has been tallied, the record is ignored. The nonstockable point tally is used to estimate the proportion of stand area associated with nonstockable openings. All stand statistics that are reported in the output are averaged across total stand area. The stand density statistics used for growth prediction, however, are averaged over only the stockable area.

Short-run prescription recommendation (*IPRSC*).—One of the Prognosis Model management options is the removal of trees marked for harvesting. A value of *IPRSC* less than or equal to 1 indicates a leave tree. Other values (*IPRSC* $\geq$ 2) indicate a tree marked for removal.

Example of tree records.—Figure 3 shows the sample tree records for the inventory of S248112. These records are organized in accordance with the default format (table 5). Table 5 also specifies the units in which data should be recorded and indicates the precision of the data to which the models were fitted.

Table 5.— Default format for tree records that are used in the Prognosis Model

Variable	Variable[1] name	Column(s)	Units	Implied decimal places[2]
Plot ID	*ITRE*	24-27	—	0
Tree count	*PROB*	31-32	trees	0
Tree history	*ITH*	33	—	0
Species	*ISP*	34-36	—	0
Diameter at breast height	*DBH*	37-39	inches	1
DBH increment	*DG*	40-41	inches	1
Live height	*HT*	45-47	feet	0
Height to topkill	*THT*	63-65	feet	0
Height increment	*HTG*	60-62	feet	1
Crown ratio code	*ICR*	48	—	0
Damage code	*IDCD*	52-53	—	0
Tree value class	*IMC*	54	—	0
Cut or leave	*IPRSC*	55	—	0

[1]Variable names are in accordance with standard FORTRAN conventions—*I, J, K, L, M,* and *N* are used to begin integer names; *ISP* is alphanumeric.

[2]For example, a *DBH* coded 115 indicates 11.5 inches. The number of decimal points indicates the precision of the data to which the models were fitted.

Reading the tree records.—Several options are available for entering tree records. Tree records are read when TREEDATA is encountered, or when PROCESS is encountered if no TREEDATA record has been previously found. The tree records are read from the dataset referenced by the number that is specified in parameter field 1 on the TREEDATA record:

TREEDATA	field 1:	Dataset reference number for tree record input file; default = 2.

The tree records can be treated like supplemental data records for the TREEDATA keyword. In this case, the dataset reference number (field 1) should be assigned the logical unit number for card input at your computer installation (logical unit 5 on most IBM systems) and a special record with *ITRE* equal to −999 must be added to the end of the tree record file. Our example tree records could be inserted into the keyword record file as follows:

```
TREEDATA      5.0
            248112    0101    011LP    11510    0734    00111
            248112    0102    011WH    06523    0308    00111
               .        .       .        .        .       .
               .        .       .        .        .       .
               .        .       .        .        .       .
            248112    0110    0111F    06614    0307    00111
                      -999
```

Another option is to treat the tree records as an independent file. This file can be stored on any medium (cards, disk, or tape) that your computer center supports. A job control statement must be created that assigns the dataset reference number indicated on the TREEDATA record to your file.[4] A programer can help you create this job control statement for your computing environment.

The last tree record input option involves merging tree record files from different sources to form a single tree record file for projection. In this case, a TREEDATA record and a job control statement for each file are required. For example, to merge the example stand (as illustrated above) with two other stands, the keyword record file might look like:

```
TREEDATA      5.0
            248112    0101    011LP    11510    0734    00111
               .        .       .        .        .       .
               .        .       .        .        .       .
               .        .       .        .        .       .
            248112    0110    011GF    06614    0307    00111
                      -999
TREEDATA     17.0
TREEDATA     18.0
```

In this example, the two additional stands are read from units 17 and 18, respectively. Separate job control statements for units 5, 17, and 18 are needed. In addition, data on the DESIGN and STDINFO keyword records must reflect the composite characteristics

[4]The data definition or DD statement in the IBM Job Control Language; the Assign file or @ASG and @USE statements in UNIVAC Job Control Language.

of the merged stand. Except for the values 2 and 5, dataset reference numbers that are less than 17 should not be used. Values that are less than 17 have been reserved for existing input and output files.

RECORD FORMAT

We have previously illustrated the default tree record format (fig. 3; table 5). It is likely, however, that your inventory records are formatted differently. Your records need not be modified prior to using the Prognosis Model. If the essential variables have been measured and recorded, the Prognosis Model input format can be altered using the TREEFMT record. This record must be inserted in the keyword record file **prior to** the TREEDATA record. The TREEFMT record does not use any parameter fields but requires two supplemental data records containing a FORTRAN execution-time format statement that describes your tree records. Both supplemental data records must immediately follow TREEFMT even though one may be blank. For example,

```
TREEFMT
(T24,I4,3X,F2.0,I1,A3,F3.1,F2.1,3X,F3.0,T63,F3.0,
T60,F3.1,T48,I1,3X,I2,2I1)
```

is the set of keyword records that specifies the default format.

SPECIES CODES

The tree records do not need to be modified when the species codes in the tree record file are different from the codes given in table 4. The way in which the Prognosis Model interprets species codes can be changed instead. This change is accomplished with the SPCODES record. The SPCODES record requires one parameter field to indicate the species for which the code is being replaced and is followed by a single supplemental record, containing the replacement code in columns one through four.

SPCODES	field 1:	Numeric species code (table 4) indicating the species for which the species code is to be replaced; if blank, replace all codes.

For example,

```
SPCODES       7.0
LPP
```

is the set of records needed to change the species code for lodgepole pine (the seventh species listed in table 4) to LPP.

When field 1 on the SPCODES record is blank, all species codes are replaced. The new codes are entered on the supplemental data record in the order that species occur in table 4 (western white pine in columns 1-4, western larch in columns 5-8, ..., mountain hemlock in columns 41-44).[5] If Forest Survey standard species codes[6] are used, the records needed to replace the species codes could be entered as follows:

```
SPCODES
119 073  202 017  263 242 108  093 019 122
```

[5]These codes are interpreted literally and blanks are not equivalent to zeroes. If all the tree records are ultimately classified as "other species" (i.e., mountain hemlock), an error has probably been made in the preparation of either the SPCODES or TREEFMT records.

[6]USDA Forest Service Handbook, 4809.11; HB-73 Tree Species.

In the above example, the spacing is important. Each code must be confined to a 4-column field, and the fields must be arranged consecutively on the supplemental record. Note also that each species can be represented by one and only one code within a tree record file.

INTERPRETING INCREMENT DATA

The final aspect we will consider with regard to the tree records is the interpretation of the periodic growth data. The projection always begins with the heights and diameters that were read as the variables *HT* and *DBH*. These variables should be measured at the same point in time. The Prognosis Model routinely assumes that *DBH* is a current outside bark diameter and that *DG* is a 10-year estimate of past inside bark diameter increment. Similarly, *HT* is assumed to be current height and *HTG* is a 5-year estimate of past height increment. These interpretations can be altered with the GROWTH record. The GROWTH record is also used to define the length of the period over which current mortality (tree history code 5) was observed. The mortality observation period is assumed to be 5 years in length.

GROWTH

field 1: Measurement method code for diameter increment data; default = 0.

field 2: Period length for diameter increment measurement; default = 10.

field 3: Measurement method code for height increment data; default = 0.

field 4: Period length for height increment measurement; default = 5.

field 5: Period length for current mortality observation; default = 5.

As was described earlier, increment estimates can be either directly measured or computed as the difference between two successive diameter or height measurements. Furthermore, the values for *DBH* and *HT* can describe the tree at either the start or the end of the growth period. Consequently, there are four possible measurement method codes, which are coded in fields 1 and/or 3 as follows:

	The time that DBH or HT was measured	
Method	**End of growth measurement period**	**Start of growth measurement period**
Increment measured directly	Code = 0	Code = 2
Increment to be calculated by subtraction	Code = 1	Code = 3

When measurement methods 1 or 3 are used, the measurements recorded for *HTG* and/or *DG* should be actual heights or outside bark diameters.

Stand Management Options

Assuming that the stand inventory has been prepared for projection, you are now ready to assess the impact of various stand management strategies. In this section, the available thinning options will be described, and we will illustrate how to use these options to simulate silvicultural treatments.

Some of the thinning options allow selection of specific trees or classes of trees for removal. In other options, a removal priority is assigned on the basis of species, size (*DBH*), and tree value class (*IMC*). The highest priority trees are then removed until a stand density target (basal area or trees per acre) is achieved. When using the stand density target options, the types of trees removed can be controlled by adjusting the relative weights of the components of the removal priority formula.

GENERAL RULES

The process of thinning involves the removal of trees. However, when thinning is simulated within the Prognosis Model, the thinned tree records are not actually eliminated from the tree record file. Rather, the number of trees per acre represented by the thinned tree records is reduced.

Cutting Efficiency

The proportion of trees represented by a tree record that can be removed in any thinning, the cutting efficiency parameter, is initially set at 0.98. If, for example, a tree record representing 300 trees per acre was removed in a thinning, the tree record would then represent six trees per acre. The cutting efficiency parameter may be changed for any or all thinnings, but the value must fall between 0.01 and 0.99. The CUTEFF record is used to change the cutting efficiency parameter:

CUTEFF	field 1:	Proportion of the sample trees represented by a record that is eliminated if a tree is designated for removal in any thinning. The value of this parameter must fall between 0.01 and 0.99 or the keyword will be ignored; the default value is 0.98.

In addition, there is a cutting efficiency parameter on each thinning request keyword. If a value is supplied as part of a thinning request, it will only apply to that thinning request. If a value is not supplied with the thinning request, the cutting efficiency parameter associated with the CUTEFF record will be used.

Date Specification

All thinnings are scheduled by date, and the date used must fall within the range of dates defined by the TIMEINT, NUMCYCLE, and INVYEAR parameters. Thinning dates need not coincide with the beginning of a cycle, however.

Any number of thinnings may be scheduled during any one projection cycle. These thinnings will be simulated in order of date. Thinnings specified for the same date will be simulated in the order they occur in the input file. For purposes of computing growth and mortality, all thinnings are assumed to occur at the beginning of the cycle in which they are scheduled.

Specifying Minimum Acceptable Harvests

Thinnings can be constrained by specifying standards for minimum acceptable harvests. These standards may be expressed in terms of volume per acre (merchantable cubic feet or board feet) or basal area per acre (square feet). Minimum harvests are specified by cycle number. The accumulated removals across **all** thinnings in a cycle must exceed the standards for **all** of the units of measure, or none of the thinnings in

that cycle will be implemented. The minimum harvest standards are specified using the MINHARV record:

MINHARV field 1: The cycle number in which minimum harvest standards will apply. If blank, the standards will be applied in all cycles.

field 2: The minimum acceptable harvest volume in merchantable cubic feet per acre; default = 0.

field 3: The minimum acceptable harvest volume in board feet per acre; default = 0.

field 4: The minimum acceptable harvest in square feet of basal area per acre; default = 0.

MODIFYING VOLUME CALCULATIONS

Both the merchantable cubic foot volume and the board foot volume indirectly influence the frequency of thinning through the minimum harvest constraints. These volume predictions also directly influence any comparison of alternative management strategies. Therefore, we have included modifications of volume calculations as a part of the general discussion of management options.

The volume calculations may be modified in two ways. First, you may choose to vary the merchantability limits on the merchantable cubic foot volume equation. Merchantable cubic foot volume is derived from total cubic foot volume by using a Behre hyperbola to approximate bole form. You may specify stump height, minimum top diameter, and minimum *DBH* to be used in estimating merchantable cubic foot volume. These factors can be altered by cycle and by species with the VOLUME record:

VOLUME field 1: Cycle number at which the merchantability limits are to take effect; default is beginning of the projection.

field 2: Species number (see table 4) for the species that is to be effected by the merchantability limits; default is all species.

field 3: Minimum merchantable *DBH* (inches). Trees with smaller *DBH* are not included in the merchantable volume calculation. If the number entered here is less than the top diameter (field 4), the value specified for minimum top diameter will be used for minimum *DBH* as well; default = 6.0 for lodgepole pine, 7.0 for all other species.

field 4: The top minimum diameter (inches); default = 4.5.

field 5: Stump height (feet); default = 1.0.

Note that the parameters on the VOLUME record do not affect the board foot volume predictions.

The other means of modifying volume predictions is by entering parameters for form and defect correction equations. Frequently, data are available which relate volume predictions to mill volume production on the basis of tree attributes. Region 1 of the Forest Service has

produced such equations for most of its National Forests and these equations are invariably polynomial expressions of tree *DBH*:

$$factor = b_0 + b_1 \cdot DBH + b_2 \cdot DBH^2 + b_3 \cdot DBH^3 + b_4 \cdot DBH^4 \qquad (1)$$

where b_0 through b_4 are species dependent coefficients.

Tree volume is then corrected for form and defect by multiplying *factor* times the predicted gross volume.

Rather than incorporating parameters in the Prognosis Model for each species, for each National Forest, and for each merchantability standard, we have provided the facility to enter parameters. A form and defect correction can be implemented for any species and for either the merchantable cubic foot or the board foot volume predictions. The parameters of the equation are entered using the MCFDPOLY (for merchantable cubic feet) or BFFDPOLY (for board feet) records.

MCFDPOLY
or
BFFDPOLY

field 1: Species number (see table 4) for which a form and defect correction factor equation is to be entered; if blank, the equation will be applied to all species.

field 2: Intercept term to be used in the form-defect correction factor equation (b_0 in eq. 1); default = 1.0

field 3: Coefficient for the *DBH* term in the form-defect correction factor equation (b_1 in eq. 1); default = 0.0

field 4: Coefficient for the DBH^2 term in the form-defect correction factor equation (b_2 in eq. 1); default = 0.0

field 5: Coefficient for the DBH^3 term in the form-defect correction factor equation (b_3 in eq. 1); default = 0.0.

field 6: Coefficient for the DBH^4 term in the form-defect correction factor equation (b_4 in eq. 1); default = 0.0

An alternative form for the form-defect correction equation is

$$\ln(V_s) = a_0 + a_1 \cdot \ln(V_0) \qquad (2)$$

where:

V_s = volume to some merchantability standard corrected for form and defect.

V_0 = uncorrected volume to the same merchantability standard.

a_0 and a_1 are species dependent coefficients.

Coefficients for the log-linear form-defect correction equation (eq. 2) can be supplied by the user. This equation may be used in addition to or instead of the polynomial form-defect correction equation. Coefficients are entered with the MCFDLN (for merchantable cubic volumes) and BFFDLN (for board foot volumes) records:

MCFDLN
or
BFFDLN — field 1: Species number (see table 4) for which the log-linear form-defect corrections equation is to be entered; if blank, the equation will be applied to all species.

field 2: Intercept term for log-linear form-defect correction equation (parameter a_0 in eq. 2); default = 0.0.

field 3: Slope coefficient for log-linear form defect correction equation (parameter a_1 in eq. 2); default = 1.0.

REQUESTING REMOVAL OF SPECIFIC TREES OR CLASSES OF TREES

The first thinning options we will consider are the prescription and diameter limit thinnings. These options allow the removal of specific trees and trees that are greater than or less than a specified limiting value of *DBH*.

Prescription Thinning

The prescription thinning option uses the marking codes (*IPRSC*) that are input with the tree records. When a prescription thinning is requested, all trees with a value of *IPRSC* that is greater than or equal to two will be removed. For example, the fourth, eighth, and 14th tree records in figure 3 were marked for removal.

Only one set of marking codes can be entered with the tree records in any one projection. Multiple requests for the prescription thinning option may lead to numerical problems within the growth projection routines unless the cutting efficiency parameter is set to a small value (say 0.5).

Prescription thinning is requested with the THINPRSC record:

THINPRSC — field 1: Year in which prescription thinning is requested; the default year is the starting date for the projection.

field 2: Cutting efficiency parameter to be used only with this thinning request. If blank, use the value specified on the CUTEFF record.

Diameter Limit Thinnings

The diameter limit thinning option can be used to remove segments of the *DBH* distribution without regard to species or tree value class. This option allows simulation of treatments such as cleaning and overwood removal (fig. 4). The diameter limit thinning option is requested with the THINDBH record:

THINDBH — field 1: Year in which diameter limit thinning is requested; the default year is the starting date for the projection.

field 2: The smallest *DBH* in the segment of the diameter distribution that is to be **removed**. If blank, remove all trees that have a *DBH* that is less than the maximum *DBH* that is coded in field 3. If both field 2 and field 3 are blank, the request is ignored.

field 3: The largest *DBH* in the segment of the diameter distribution that is to be **removed**. If blank, remove all trees that have a *DBH* that is greater than the minimum *DBH* that is coded in field 2. If both field 2 and field 3 are blank, the request is ignored.

field 4: Cutting efficiency parameter to be used only with this thinning request; if blank, use the value specified on the CUTEFF record.

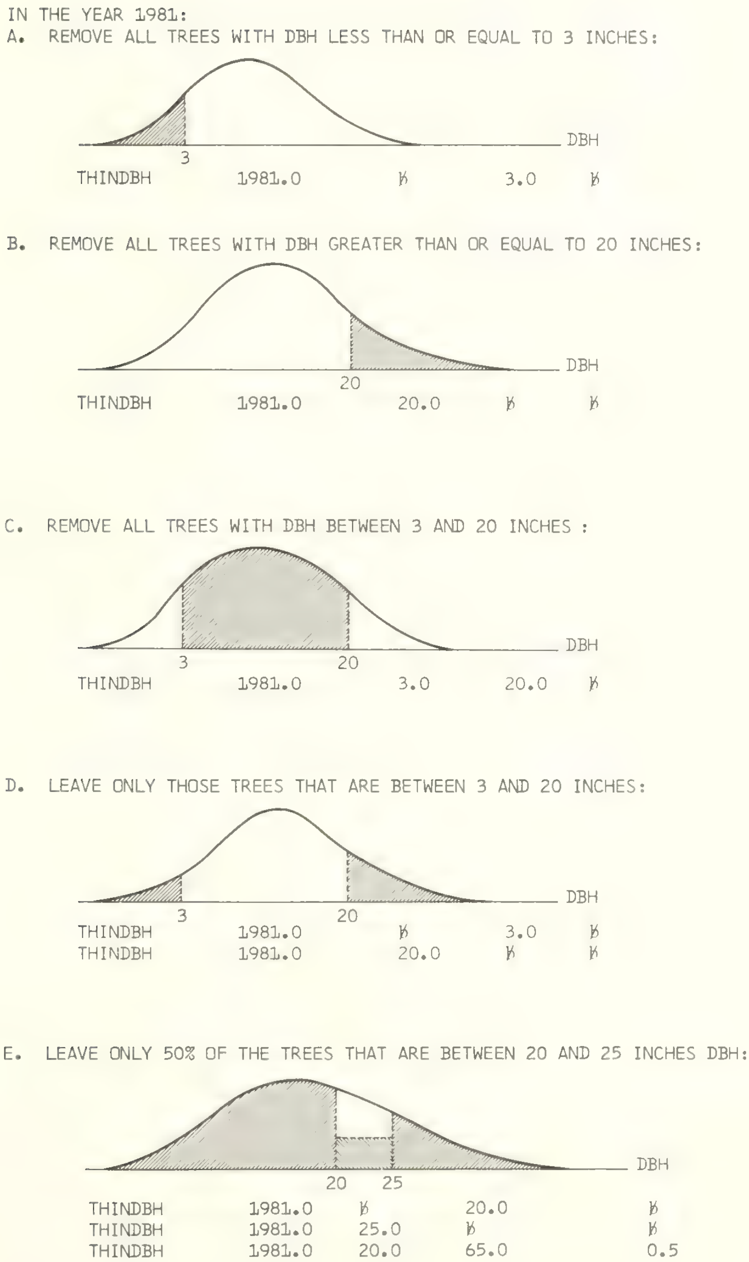


Figure 4.—Using the THINDBH record to remove specific segments of the *DBH* distribution; five examples.

CONTROLLING STAND DENSITY

The remaining stand management options reflect a somewhat different management philosophy. With these options stand density may be managed while giving consideration to tree size, species, and value class in determining priority for removal. The thinning request keyword specifies whether basal area per acre or trees per acre will be controlled. It also indicates whether small trees (thinning from below) or large trees (thinning from above) will be favored for removal. Other keywords are needed to specify the role of species and tree condition in determining the actual removal priority.

Computing Removal Priority

Each tree is assigned a priority for removal (P) that is computed as

$$P = (S \cdot DBH) + SP + (T \cdot IMC) \qquad (3)$$

where:

$S = (-1)$ if thinning from below
$(+1)$ if thinning from above

SP = User-specified species preference

IMC = input tree value class code

T = user-specified multiplier for the tree value class code.

The probability that a tree will be removed in a thinning is proportional to P. The tree with the largest P is removed first. Thereafter, trees are selected for removal, in descending order of P, until the residual stand density objective is achieved. By manipulating the values of SP and T and choosing an appropriate density control option, a thinning strategy can be designed to attain almost any silvicultural objective.

The default value of SP is zero for all species and the default value of T is 100. If these parameters are not altered by input, all tree value class 3 trees will be removed prior to removal of any class 1 or 2 trees, and all class 2 trees will be removed before any class 1 trees. Within a tree value class, the trees will be ordered by DBH.

The SPECPREF and TCONDMLT records can be used to modify the values of SP and T, respectively:

SPECPREF

field 1: Date that the species preference code given on this record will take effect. If blank, it will be implemented at the start of the projection.

field 2: **Numeric** species code as given in table 4; the request is ignored if species code is invalid or missing.

field 3: Species preference code, SP. Any value may be used: negative values will decrease the probability of removal for a species; positive values will increase the probability of removal for a species; default = 0.

TCONDMLT field 1: Date that the tree condition class multiplier coded on this record will take effect. If blank, it will be implemented at the start of the projection.

field 2: Tree condition class multiplier, T; default = 100.0.

The SPECPREF and TCONDMLT records are scheduled along with thinning requests. As we described earlier, scheduling is determined by date, and within date, by order of occurrence in the input file. Once the preference modifiers are set, they will remain in effect until replaced with new SPECPREF or TCONDMLT instructions.

Specifying Thinning Method and Target Density

The keywords used to specify a stand density target also indicate whether thinnings are to be from above or from below. These keywords are defined as follows:

(1) THINBTA— Thin from below to a trees-per-acre target.

(2) THINATA— Thin from above to a trees-per-acre target.

(3) THINBBA— Thin from below to a basal-area-per-acre target (square feet).

(4) THINABA— Thin from above to a basal-area-per-acre target (square feet).

With the exception of the unit of measure for the residual density, the same parameters must be entered on all of these keyword records:

THINBTA
THINATA
THINBBA
THINABA field 1: Year in which thinning is requested; if blank, schedule at start of projection.

field 2: The desired residual stand density measured in the appropriate units. If a residual density is not specified, the thinning request will be ignored.

field 3: The cutting efficiency parameter to be used only with this thinning request. If blank, use the value specified on the CUTEFF record.

Each tree record is considered for thinning only once per thinning request. If the cutting efficiency parameter is set at a relatively low level, it is possible that a thinning will be simulated without achieving the specified stand density target.

Automatic Stand Density Control

The last thinning option allows you to automatically maintain stand density within a specific range of trees per acre that is based on normal stocking. Normal stocking, in trees per acre (T_N), is predicted as a function of quadratic mean stand DBH (QMD)

$$T_N = \frac{1}{0.00004 \cdot (1 + QMD)^{1.588}} \tag{4}$$

The normal stocking function (fig. 5) was fit to data in Haig's (1932) yield tables but is intended only as a guide curve. The equation form is quite similar to Reineke's (1933) stand density index.

When automatic density control is used, the upper and lower limits of stand density (*MIN* and *MAX*) are defined as percentages of normal stocking. If, at the beginning of a cycle, the stand density is greater than *MAX* percent of normal, the number of trees in the stand will be reduced to *MIN* percent of normal by thinning from below. The removal priority as defined by SPECPREF and TCONDMLT (eq. 3) will determine the order of removal.

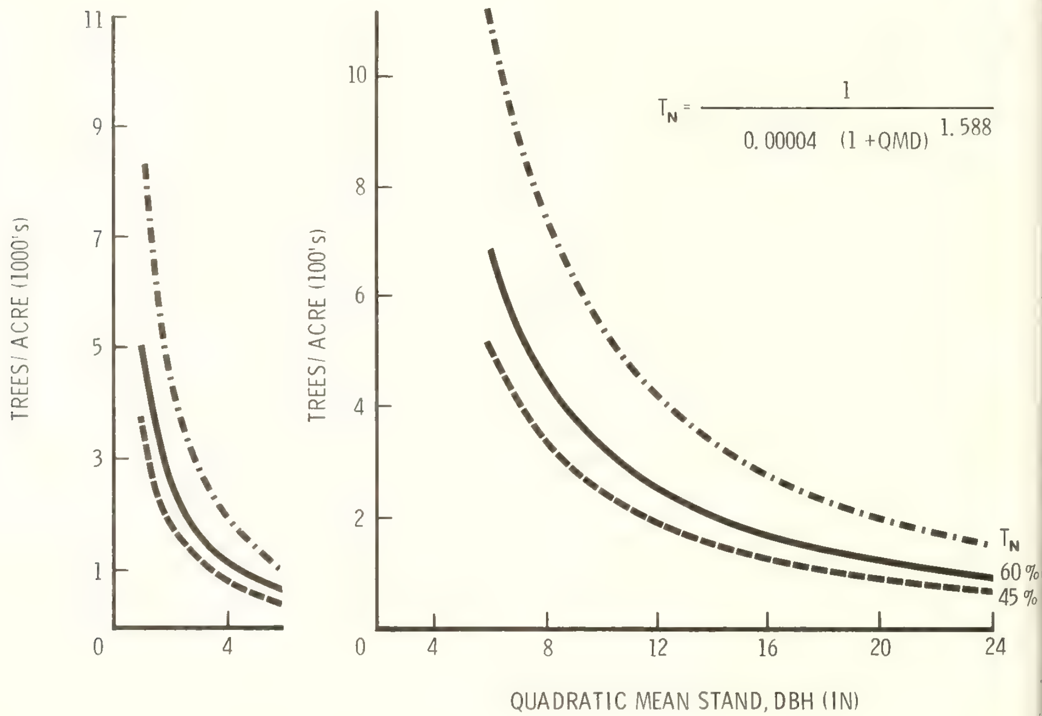


Figure 5.—Normal stocking density in trees per acre (T_N) as a function of quadratic mean stand *DBH* (*QMD*). Based on Haig's (1932) yield tables for second-growth stands in the western white pine type.

Automatic density control may be started at the beginning of the projection or delayed for any number of years. Once initiated, automatic control will be implemented in each subsequent cycle for which there is no other thinning request.

Automatic density control is requested with the THINAUTO record:

THINAUTO	field 1:	The date that automatic density control is to start; default = start of projection.
	field 2:	The lower limit (*MIN*) of the range of normal stocking density that is to be maintained; default = 45 percent.
	field 3:	The upper limit (*MAX*) of the range of normal stocking density that is to be maintained; default = 60 percent.
	field 4:	The cutting efficiency parameter to be used with all removals invoked with this request. If blank, use the value specified on the CUTEFF record.

A PRESCRIPTION FOR THE EXAMPLE STAND

We prepared some additional summaries of our example stand (table 6) and showed them to a certified silviculturist.[7] He prepared the following prescription:

(1) Implement the thinning indicated by the input tree marking codes (fig. 3) at age 60 (assumed to be 1980).
(2) At age 90, remove lodgepole pine and western larch. These species can be expected to be dominated by the Douglas-fir and grand fir in the future.
(3) At age 120, initiate a shelterwood regeneration treatment favoring the Douglas-fir and grand fir.
(4) Remove overwood at age 130 to release established regeneration.

To implement the first phase of the prescription, we need only use:

```
THINPRSC        1980.0
```

Table 6.— Additional summary data for stand S248112[1]

Species	Trees per acre	Basal area per acre	Quadratic mean *DBH*	Average height[3]	Average 10-year *DBH* increment[3]
		Stand composition before thinning (1980)[2]			
		*Ft*²	*Inches*	*Feet*	*Inches*
LP	28.9	14.56	9.6	63.3	0.77
WH	15.8	3.64	6.5	23.0	2.30
L	40.5	14.56	8.1	67.8	.84
GF	163.5	18.20	4.5	19.1	1.30
DF	188.1	17.69	4.2	15.2	1.32
C	182.8	8.81	3.0	10.4	.85
All	619.6	77.46	4.8	20.7	1.13
		Projected Prescription Removal (1980)			
LP	7.2	3.64	9.6	60.0	.50
L	10.4	3.64	8.0	63.0	.70
GF	81.8	0.0	0.1	3.0	—
DF	142.5	4.39	2.4	8.1	.90
C	136.4	1.53	1.4	5.0	.60
All	378.3	13.20	2.5	8.4	.64
		Prescribed Residual Stand (1980)			
LP	21.7	10.92	9.6	65.3	1.06
WH	15.8	3.64	6.5	23.0	2.30
L	30.1	10.92	8.2	70.2	.89
GF	81.7	18.20	6.4	35.2	1.30
DF	45.6	13.30	7.3	37.4	1.46
C	46.4	7.28	5.4	26.3	1.00
All	241.3	64.26	7.0	37.8	1.27

[1]Location, St. Joe National Forest; habitat type, 570; elevation, 3400 ft; slope, 25 to 35 percent; aspect, northwest; age 57 years (1977 inventory).
[2]These statistics were based entirely on the inventory data used as input to the Prognosis Model.
[3]When variables are subsampled, the average includes only those trees for which the variable was measured.

[7]Russell T. Graham, U.S. Department of Agriculture Forest Service, INT-RWU-1206; certified through USDA Forest Service, Region 1 CEFES program. What he actually told us was to leave the stand alone, as it was well stocked. Because that prescription would have made a poor example, we embellished it a little.

The second phase of the prescription requires a little analysis. We can see from table 6 that, following the prescription thinning, there will be approximately 240 trees per acre, and 58 trees will be lodgepole pine and western larch (LP-L). The local rule-of-thumb predicts 0.5 percent mortality per year. This converts to about 14 percent mortality in 30 years; so, by age 90, we might expect 34 total trees to have died, of which 8 would be LP-L. This leaves us with approximately 207 trees, of which 50 are LP-L and 157 are of other species. The LP and L can be removed using:

```
SPECPREF    2010.0       2.0      999.0
SPECPREF    2010.0       7.0     9999.0
THINBTA     2010.0     157.0
```

We considered the lodgepole pine to be less desirable and weighted it heavier to assure its removal.

To implement the third phase of the prescription, we need to define a shelterwood and then protect the Douglas-fir (species number 3) and grand fir (species number 4) from harvesting. A shelterwood is defined as a residual stand with about 35 trees per acre. Thus,

```
SPECPREF    2040.0       3.0     -999.0
SPECPREF    2040.0       4.0      -99.0
THINBTA     2040.0      35.0
```

should produce the desired results. We have indicated a slight preference for keeping Douglas-fir over grand fir.

The final phase of the prescription requires no additional keywords unless a model has actually been used to predict the establishment of regeneration. In this case,

```
THINDBH     2050.0       5.0          b̸
```

will remove all trees with *DBH* greater than 5 inches, leaving the regenerated stand.

If we wished to project the development of the regenerated stand, we could use automatic density control to maintain stand density. In this example, we will initiate automatic density control after overwood removal and then reduce trees per acre to 50 percent of normal any time it exceeds 75 percent of normal:

```
THINAUTO    2060.0      50.0       75.0
```

INTERPRETING PROGNOSIS MODEL OUTPUT

When a projection begins, the keyword record file is processed and an activity schedule is prepared. The tree records are then checked for missing data and the growth models are calibrated based on the input increment data. The results of these activities are displayed in the first output table (fig. 6).

As events in the activity schedule are simulated, three additional output tables are prepared. The first of these is the stand composition table (fig. 7). Here, the distributions of important stand attributes are displayed relative to *DBH* and species. At each cycle endpoint, the per-acre distributions of trees and total cubic volume are described. In addition, total stand volume is displayed for two different utilization standards: cubic foot volume with user provided top diameter, minimum *DBH*, and stump height specifications; and Scribner board foot volume to an 8-inch top, assuming a 1-foot stump and a 9-inch minimum *DBH*. Simulated removals are described with the same statistics and the distribution of trees in the residual stand is then given. Development of the stand is shown by the distributions of volume accretion and volume mortality, both measured in total cubic feet. Accretion is the growth on surviving trees.

The stand composition table is complemented by a table that features the development of individual trees within the stand. In this table (fig. 8), the attributes of six trees are displayed along with several statistics that describe the stand conditions in which the trees developed. The sample trees represent a cross section of the population of trees within the stand and the same trees are displayed each cycle. The statistics printed include species and tree value class, *DBH*, height, crown ratio, past periodic *DBH* increment, percentile in the basal area distribution, and trees per acre represented by the record. The stand is described with an age estimate, three density statistics (basal area, crown competition factor, and trees per acre), estimates of average *DBH*, and average dominant height. The stand statistics, excluding age, are repeated for the residual stand if a removal is simulated.

The last standard output table is a summary of stand development and management activity (fig. 9). This table repeats stand statistics from the previous tables in a concise yield table format with one line allotted to each date in the activity schedule.

Two optional tables can be selected by using the appropriate keyword records. The summary table (fig. 9) may be copied to a permanent storage device for subsequent machine processing (use the ECHOSUM record). In addition, a table that shows the attributes of all sample trees can be printed at each cycle endpoint (see the discussion of TREELIST). Output can also be generated to assist with program debugging. This special output is described in appendix A.

```
---------------------------------------------------------------------------------------------

                              OPTIONS SELECTED BY INPUT

---------------------------------------------------------------------------------------------
KEYWORD    PARAMETERS:
--------   ----------------------------------------------------------------------------------

STDIDENT
           STAND ID= S248112          HYPOTHETICAL PRESCRIPTION FOR USER'S MANUAL -- NIG4 VERSION

COMMENT
             THE PRESCRIPTION CALLS FOR IMMEDIATE REMOVAL OF
             EXCESS TREES, A COMMERCIAL THINNING AT AGE 90
             TO REMOVE LODGEPOLE AND LARCH, A SHELTERWOOD
             REGENERATION TREATMENT AT AGE 120 FAVORING
             GRAND FIR AND DOUGLAS-FIR, AND AN OVERWOOD
             REMOVAL AT AGE 130.

END

TREELIST   CYCLE=   1

DESIGN     BASAL AREA FACTOR=  40.0; INVERSE OF FIXED PLOT AREA=  300.0; BREAK DBH=    5.0
           SEE "OPTIONS SELECTED BY DEFAULT" FOR REMAINING DESIGN CARD PARAMETERS.

STDINFO    FOREST CODE= 18; HABITAT TYPE=570; AGE=   57; ASPECT CODE=  8.; SLOPE CODE=  3.
           ELEVATION(100'S FEET)= 34.0; SITE INDEX=   0.

INVYEAR    INVENTORY YEAR= 1977

NUMCYCLE   NUMBER OF CYCLES=  8

THINPRSC   DATE/CYCLE= 1980; PROPORTION OF SELECTED TREES REMOVED= 0.999

SPECPREF   DATE/CYCLE= 2010; SPECIES=  2.; THINNING SELECTION PRIORITY=  999.

SPECPREF   DATE/CYCLE= 2010; SPECIES=  7.; THINNING SELECTION PRIORITY= 9999.

THINBTA    DATE/CYCLE= 2010; RESIDUAL=  157.00; PROPORTION OF SELECTED TREES REMOVED= 0.980

SPECPREF   DATE/CYCLE= 2040; SPECIES=  3.; THINNING SELECTION PRIORITY  -999.

SPECPREF   DATE/CYCLE= 2040; SPECIES=  4.; THINNING SELECTION PRIORITY=  -99.

THINBTA    DATE/CYCLE= 2040; RESIDUAL=   35.00; PROPORTION OF SELECTED TREES REMOVED= 0.980

TREEDATA   DATA SET REFERENCE NUMBER=  5

PROCESS    PROCESS THE STAND.
---------------------------------------------------------------------------------------------



                              OPTIONS SELECTED BY DEFAULT
---------------------------------------------------------------------------------------------

TREEFMT    (23X,I4,3X, F2.0,I1, A3,F3.1,F2.1,3X,F3.0,T63,F3.0   ,T60,F3.1,T48,  I1,3X, I2,
           2I1)

DESIGN     BASAL AREA FACTOR= 40.0; INVERSE OF FIXED PLOT AREA=  300.0; BREAK DBH=    5.0
           NUMBER OF PLOTS=    11; NON-STOCKABLE PLOTS=     1; STAND SAMPLING WEIGHT=  11.00000
---------------------------------------------------------------------------------------------

                              ACTIVITY SCHEDULE

STAND ID= S248112    MANAGEMENT ID= NONE     HYPOTHETICAL PRESCRIPTION FOR USER'S MANUAL -- NIG4 VERSION
---------------------------------------------------------------------------------------------
```

```
CYCLE  DATE  EXTENSION  KEYWORD   DATE  PARAMETERS:
-----  ----  ---------  --------  ----  ------------------------------------------------------------------------

  1    1977
              BASE      THINPRSC  1980        1.00

  2    1987
  3    1997

  4    2007
              BASE      SPECPREF  2010        2.00      999.00
              BASE      SPECPREF  2010        7.00     9999.00
              BASE      THINBTA   2010      157.00        0.98

  5    2017
  6    2027

  7    2037
              BASE      SPECPREF  2040        3.00     -999.00
              BASE      SPECPREF  2040        4.00      -99.00
              BASE      THINBTA   2040       35.00        0.98

  8    2047
----------------------------------------------------------------------------------------------------------------


CALIBRATION STATISTICS:

                                                  LP     DF     WH     L      GF     C
                                                 ----   ----   ----   ----   ----   ----

NUMBER OF RECORDS PER SPECIES                       5      8      1      4      6      4

NUMBER OF RECORDS CODED AS RECENT MORTALITY         1      0      0      0      0      0

NUMBER OF RECORDS WITH MISSING HEIGHTS              1      0      0      0      0      0

NUMBER OF RECORDS WITH BROKEN OR DEAD TOPS          0      1      0      1      0      0

NUMBER OF RECORDS WITH MISSING CROWN RATIOS         0      0      0      0      0      0

NUMBER OF RECORDS AVAILABLE FOR SCALING
THE DIAMETER INCREMENT MODEL                        3      4      1      3      5      2

RATIO OF STANDARD ERRORS
(INPUT DBH GROWTH DATA : MODEL)                  0.84   0.74   1.00   0.42   0.87   0.72

WEIGHT GIVEN TO THE INPUT GROWTH DATA WHEN
DBH GROWTH MODEL SCALE FACTORS WERE COMPUTED     1.00   1.00   0.0    1.00   1.00   1.00

INITIAL SCALE FACTORS FOR THE
DBH INCREMENT MODEL                              0.92   0.65   1.00   0.68   0.46   0.76

NUMBER OF RECORDS AVAILABLE FOR SCALING
THE SMALL TREE HEIGHT INCREMENT MODEL               0      3      0      0      0      1

INITIAL SCALE FACTORS FOR THE SMALL TREE
HEIGHT INCREMENT MODEL                           1.00   0.76   1.00   1.00   1.00   1.00
```

Figure 6.—Input summary and calibration statistics table from the Prognosis Model output.

STAND ID: S248112 MANAGEMENT CODE: NONE HYPOTHETICAL PRESCRIPTION FOR USER'S MANUAL -- NIG4 VERSION

STAND COMPOSITION

YEAR	STAND ATTRIBUTES	10	30	50	70	90	100	TOTAL/ACRE OF STAND ATTRIBUTES	DISTRIBUTION OF STAND ATTRIBUTES BY SPECIES AND 3 USER-DEFINED SUBCLASSES			
		PERCENTILE POINTS IN THE DISTRIBUTION OF STAND ATTRIBUTES BY DBH (DBH IN INCHES)										
1977	TREES	0.1	0.1	3.2	6.1	8.5	12.7	536. TREES	27.% DF2,	15.% GF2,	15.% GF1,	10.% C2
	VOLUME:											
	TOTAL	5.8	8.0	9.4	10.0	11.5	12.7	1541. CUFT	23.% LP1,	20.% GF1,	19.% DF1,	12.% L1
	MERCH	8.0	8.5	9.6	10.4	11.5	12.7	1075. CUFT	31.% LP1,	23.% DF1,	14.% L1,	9.% LP2
	MERCH	9.5	9.6	10.4	11.5	12.7	12.7	2804. BDFT	35.% LP1,	29.% DF1,	15.% LP2,	13.% GF1
	REMOVAL	0.1	0.1	0.1	1.2	3.2	10.4	296. TREES	48.% DF2,	28.% GF2,	18.% C2,	4.% L2
	VOLUME:											
	TOTAL	8.0	8.0	9.6	9.6	10.4	10.4	290. CUFT	38.% LP2,	30.% L2,	29.% DF2,	3.% C2
	MERCH	8.0	8.0	9.6	9.6	10.4	10.4	250. CUFT	40.% LP2,	31.% L2,	29.% DF2,	0.% ---
	MERCH	9.6	9.6	9.6	10.4	10.4	10.4	645. BDFT	66.% LP2,	34.% DF2,	0.% ---,	0.% ---
	RESIDUAL	4.0	5.3	6.2	7.9	9.5	12.7	240. TREES	33.% GF1,	19.% C1,	19.% DF1,	13.% L1
	ACCRETION	5.3	6.1	6.6	9.4	10.9	12.7	82. CUFT/YR	34.% GF1,	20.% DF1,	14.% LP1,	11.% L1
	MORTALITY	5.8	6.5	8.4	9.5	11.5	12.7	8. CUFT/YR	28.% GF1,	27.% LP1,	18.% DF1,	15.% L1
1987	TREES	5.5	6.8	8.0	9.3	11.3	15.5	223. TREES	33.% GF1,	20.% C1,	19.% DF1,	13.% L1
	VOLUME:											
	TOTAL	6.8	8.7	9.5	11.3	13.3	15.5	1991. CUFT	29.% GF1,	23.% LP1,	22.% DF1,	13.% L1
	MERCH	7.6	9.2	10.2	11.9	13.3	15.5	1627. CUFT	26.% GF1,	26.% LP1,	22.% DF1,	14.% L1
	MERCH	9.3	10.3	11.3	12.4	13.6	15.5	4645. BDFT	38.% LP1,	31.% DF1,	16.% GF1,	10.% L1
	ACCRETION	6.7	7.6	9.2	10.2	12.4	15.5	106. CUFT/YR	39.% GF1,	19.% DF1,	11.% LP1,	11.% WH1
	MORTALITY	6.8	8.7	9.4	11.3	12.8	15.5	12. CUFT/YR	30.% GF1,	21.% LP1,	18.% DF1,	13.% WH1
1997	TREES	7.0	8.3	9.5	10.8	13.2	18.2	209. TREES	33.% GF1,	20.% C1,	19.% DF1,	13.% L1
	VOLUME:											
	TOTAL	8.3	9.8	11.0	12.6	14.6	18.2	2934. CUFT	32.% GF1,	21.% DF1,	18.% LP1,	12.% L1
	MERCH	8.6	10.0	11.1	12.8	15.0	18.2	2648. CUFT	33.% GF1,	20.% DF1,	19.% LP1,	12.% L1
	MERCH	9.8	10.8	11.9	13.7	15.3	18.2	9128. BDFT	28.% GF1,	25.% LP1,	23.% DF1,	12.% L1
	ACCRETION	8.1	9.3	10.6	11.8	14.5	18.2	114. CUFT/YR	39.% GF1,	19.% DF1,	13.% WH1,	11.% LP1
	MORTALITY	8.3	9.9	11.1	13.0	15.0	18.2	18. CUFT/YR	32.% GF1,	19.% LP1,	17.% DF1,	16.% WH1
2007	TREES	7.7	9.6	10.8	11.8	14.8	19.3	196. TREES	33.% GF1,	20.% C1,	19.% DF1,	13.% L1
	VOLUME:											
	TOTAL	9.2	10.8	11.9	14.5	16.3	19.3	3887. CUFT	34.% GF1,	21.% DF1,	16.% LP1,	10.% L1
	MERCH	9.3	11.0	12.0	14.7	16.4	19.3	3606. CUFT	35.% GF1,	20.% DF1,	17.% LP1,	10.% L1
	MERCH	10.4	11.6	12.4	14.8	16.9	19.3	14518. BDFT	35.% GF1,	20.% DF1,	18.% LP1,	10.% WH1
	REMOVAL	10.0	10.5	11.0	11.5	13.5	15.5	39. TREES	55.% L1,	45.% LP1,	0.% L2,	0.% LP2
	VOLUME:											
	TOTAL	10.0	10.7	11.5	12.8	14.7	15.5	945. CUFT	66.% LP1,	34.% L1,	0.% LP2,	0.% L2
	MERCH	10.0	10.7	11.5	12.8	14.7	15.5	895. CUFT	66.% LP1,	34.% L1,	0.% LP2,	0.% L2
	MERCH	10.0	10.7	11.5	13.1	14.9	15.5	3765. BDFT	70.% LP1,	30.% L1,	0.% LP2,	0.% L2
	RESIDUAL	7.6	9.2	10.8	11.9	15.2	19.3	157. TREES	41.% GF1,	25.% C1,	24.% DF1,	7.% WH1

	ACCRETION	9.2	10.4	11.7	13.7	16.8	19.3	128.	CUFT/YR	55.% GF1,	16.% DF1,	14.% WH1,	13.% C1
	MORTALITY	9.2	11.6	12.7	15.3	16.9	19.3	19.	CUFT/YR	44.% GF1,	23.% WH1,	22.% DF1,	8.% C1
2017	TREES	8.5	10.9	12.7	13.6	16.8	22.4	148.	TREES	41.% GF1,	26.% C1,	24.% DF1,	6.% WH1
	VOLUME:												
	TOTAL	10.4	12.8	13.8	15.8	18.4	22.4	4032.	CUFT	49.% GF1,	24.% DF1,	13.% C1,	12.% WH1
	MERCH	10.7	12.9	14.0	16.3	18.4	22.4	3829.	CUFT	49.% GF1,	24.% DF1,	12.% WH1,	12.% C1
	MERCH	11.5	12.9	14.1	16.5	18.9	22.4	16871.	BDFT	52.% GF1,	22.% DF1,	14.% WH1,	9.% C1
	ACCRETION	10.4	12.7	13.1	14.3	17.8	22.4	136.	CUFT/YR	55.% GF1,	17.% C1,	16.% DF1,	10.% WH1
	MORTALITY	11.3	12.9	14.2	17.3	19.9	22.4	26.	CUFT/YR	46.% GF1,	24.% WH1,	20.% DF1,	8.% C1
2027	TREES	9.5	11.2	14.1	15.7	18.2	23.9	139.	TREES	41.% GF1,	26.% C1,	24.% DF1,	6.% WH1
	VOLUME:												
	TOTAL	11.2	14.2	15.7	17.3	20.2	23.9	5126.	CUFT	50.% GF1,	22.% DF1,	14.% C1,	11.% WH1
	MERCH	11.2	14.2	15.7	17.4	20.2	23.9	4914.	CUFT	51.% GF1,	22.% DF1,	14.% C1,	11.% WH1
	MERCH	11.9	14.3	15.7	17.5	20.4	23.9	23122.	BDFT	53.% GF1,	21.% DF1,	12.% WH1,	11.% C1
	ACCRETION	11.7	14.3	15.6	17.3	20.0	23.9	157.	CUFT/YR	53.% GF1,	18.% C1,	14.% WH1,	13.% DF1
	MORTALITY	11.9	14.4	16.2	18.2	21.3	23.9	34.	CUFT/YR	49.% GF1,	21.% WH1,	19.% DF1,	9.% C1
2037	TREES	10.0	12.1	15.1	17.7	19.4	26.0	131.	TREES	41.% GF1,	27.% C1,	25.% DF1,	5.% WH1
	VOLUME:												
	TOTAL	12.1	15.5	17.7	18.9	22.4	26.0	6351.	CUFT	51.% GF1,	20.% DF1,	15.% C1,	11.% WH1
	MERCH	12.2	15.5	17.7	18.9	22.4	26.0	6127.	CUFT	52.% GF1,	20.% DF1,	15.% C1,	11.% WH1
	MERCH	12.6	15.8	17.8	19.1	22.4	26.0	29948.	BDFT	54.% GF1,	19.% DF1,	13.% WH1,	13.% C1
	REMOVAL	10.4	13.3	15.3	17.8	19.1	26.0	96.	TREES	54.% GF1,	36.% C1,	7.% WH1,	3.% L1
	VOLUME:												
	TOTAL	12.5	15.6	17.6	18.4	22.4	26.0	4846.	CUFT	63.% GF1,	20.% C1,	15.% WH1,	2.% L1
	MERCH	12.5	15.7	17.6	18.4	22.4	26.0	4676.	CUFT	64.% GF1,	19.% C1,	15.% WH1,	2.% L1
	MERCH	13.3	15.7	17.7	18.7	22.4	26.0	23273.	BDFT	65.% GF1,	17.% WH1,	16.% C1,	2.% L1
	RESIDUAL	8.0	10.0	11.6	16.5	19.9	26.0	35.	TREES	92.% DF1,	5.% GF1,	2.% C1,	0.% WH1
	ACCRETION	10.0	12.6	16.5	19.2	22.9	26.0	33.	CUFT/YR	83.% DF1,	13.% GF1,	2.% C1,	1.% WH1
	MORTALITY	10.4	15.5	18.9	20.4	23.2	26.0	7.	CUFT/YR	80.% DF1,	16.% GF1,	2.% WH1,	1.% C1
2047	TREES	8.4	11.7	12.6	17.5	21.2	27.5	33.	TREES	92.% DF1,	5.% GF1,	2.% C1,	0.% WH1
	VOLUME:												
	TOTAL	11.7	16.0	19.5	20.9	24.3	27.5	1760.	CUFT	85.% DF1,	12.% GF1,	1.% C1,	1.% WH1
	MERCH	11.8	16.0	19.5	20.9	24.6	27.5	1703.	CUFT	85.% DF1,	13.% GF1,	1.% C1,	1.% WH1
	MERCH	12.6	17.3	20.1	21.2	24.7	27.5	8034.	BDFT	83.% DF1,	14.% GF1,	1.% C1,	1.% WH1
	ACCRETION	8.4	12.8	17.5	20.2	24.0	27.5	51.	CUFT/YR	84.% DF1,	13.% GF1,	2.% C1,	1.% WH1
	MORTALITY	12.0	16.8	20.0	21.2	24.7	27.5	9.	CUFT/YR	80.% DF1,	16.% GF1,	2.% WH1,	1.% C1
2057	TREES	10.5	12.8	14.1	20.3	23.6	29.6	32.	TREES	92.% DF1,	5.% GF1,	2.% C1,	0.% WH1
	VOLUME:												
	TOTAL	12.8	18.0	21.1	23.3	26.9	29.6	2183.	CUFT	85.% DF1,	12.% GF1,	2.% C1,	1.% WH1
	MERCH	12.8	18.0	21.1	23.3	26.9	29.6	2123.	CUFT	85.% DF1,	13.% GF1,	2.% C1,	1.% WH1
	MERCH	13.5	18.1	21.1	23.3	26.9	29.6	10684.	BDFT	84.% DF1,	13.% GF1,	1.% C1,	1.% WH1

Figure 7.—Stand composition table from the Prognosis Model output.

STAND ID: S248112 MANAGEMENT CODE: NONE HYPOTHETICAL PRESCRIPTION FOR USER'S MANUAL -- NIG4 VERSION

	ATTRIBUTES OF SELECTED SAMPLE TREES								ADDITIONAL STAND ATTRIBUTES					
YEAR	INITIAL TREES/A %TILE	SPECIES	DBH (INCHES)	HEIGHT (FEET)	LIVE CROWN RATIO	PAST DBH GROWTH (INCHES)	BASAL AREA %TILE	TREES PER ACRE	STAND AGE	QUADRATIC MEAN DBH (INCHES)	TREES PER ACRE	BASAL AREA (SQFT/A)	HEIGHT OF DOMINANTS (FEET)	CROWN COMP FACTOR
1977						(10 YRS)								
	10	GF2	0.10	3.00	65	0.0	0.0	81.82						
	30	DF2	0.10	2.00	55	0.0	0.0	81.82						
	50	C2	3.20	17.00	45	0.60	3.0	27.27						
	70	GF1	6.10	38.00	75	1.20	24.8	17.92						
	90	LP1	8.50	62.54	25	0.0	62.4	9.23						
	100	DF1	12.70	67.00	35	1.60	100.0	4.13	57	5.1	536.	77.	63.0	99.8
									RESIDUAL:	7.0	240.	64.	64.3	83.8
1987						(10 YRS)								
	10	GF2	0.63	8.69	65	0.49	0.0	0.07						
	30	DF2	0.65	7.39	55	0.48	0.0	0.07						
	50	C2	4.83	23.68	45	1.55	0.5	0.03						
	70	GF1	7.65	49.76	75	1.42	28.7	16.58						
	90	LP1	9.32	69.22	23	0.80	55.2	8.68						
	100	DF1	13.98	75.40	33	1.11	98.6	3.95	67	8.6	223.	89.	70.6	112.1
1997						(10 YRS)								
	10	GF2	2.21	16.08	65	1.44	0.0	0.07						
	30	DF2	2.49	14.99	55	1.59	0.0	0.07						
	50	C2	6.28	30.11	46	1.37	0.8	0.02						
	70	GF1	9.25	61.12	73	1.47	27.7	15.47						
	90	LP1	10.07	75.50	19	0.73	43.7	8.21						
	100	DF1	15.27	83.35	30	1.12	95.1	3.76	77	10.1	209.	115.	76.6	139.0
2007						(10 YRS)								
	10	GF2	4.39	24.33	68	1.99	0.0	0.06						
	30	DF2	4.73	23.95	57	1.95	0.0	0.06						
	50	C2	8.48	37.08	53	2.10	7.2	0.02						
	70	GF1	11.82	73.65	74	2.35	53.0	14.52						
	90	LP1	10.68	81.20	16	0.59	30.6	7.75						
	100	DF1	17.68	92.68	29	2.09	97.0	3.57	87	11.3	196.	136.	81.6	157.6
									RESIDUAL:	11.2	157.	108.	81.4	130.9
2017						(10 YRS)								
	10	GF2	6.58	34.21	70	2.01	0.0	0.06						
	30	DF2	7.05	35.65	62	2.01	0.1	0.06						
	50	C2	9.64	43.52	55	1.10	10.3	0.02						
	70	GF1	14.08	85.13	75	2.07	60.4	13.63						
	90	LP1	11.17	86.34	15	0.47	16.4	0.15						
	100	DF1	18.39	98.24	28	0.62	91.4	3.38	97	12.8	148.	132.	88.4	151.3
2027						(10 YRS)								
	10	GF2	7.32	42.89	72	0.67	0.1	0.05						
	30	DF2	9.28	47.66	72	1.93	3.1	0.05						
	50	C2	11.09	50.46	55	1.37	12.4	0.02						
	70	GF1	15.70	94.88	73	1.49	55.6	12.78						
	90	LP1	11.78	91.72	14	0.59	15.7	0.14						
	100	DF1	18.83	102.81	26	0.39	87.3	3.20	107	14.2	139.	152.	91.1	169.4
2037						(10 YRS)								
	10	GF2	9.31	53.72	77	1.82	1.9	0.05						
	30	DF2	10.33	56.82	71	0.91	4.3	0.05						
	50	C2	12.59	57.48	55	1.43	16.7	0.02						
	70	GF1	17.86	105.17	72	1.97	59.0	11.95						
	90	LP1	12.25	96.53	13	0.46	13.9	0.13						
	100	DF1	19.33	107.41	24	0.43	78.9	3.02	117	15.5	131.	172.	99.3	189.1
									RESIDUAL:	14.4	35.	40.	112.7	40.4

```
2047                                      ( 10 YRS)
       10     GF2     10.18     63.09   88     0.80     6.0    0.00
       30     DF2     13.14     69.02   87     2.43    24.3    0.05
       50      C2     14.01     64.28   58     1.35    24.7    0.00
       70     GF1     18.86    112.56   82     0.91    49.9    0.22
       90     LP1     13.60    103.19   20     1.31    24.5    0.00
      100     DF1     20.86    113.92   32     1.33    75.7    2.87
                                                                      127     15.6     33.     44.     118.5     43.4

2057                                      ( 10 YRS)
       10     GF2     10.99     71.34   88     0.74     7.5    0.00
       30     DF2     16.42     80.52   88     2.85    30.0    0.05
       50      C2     16.38     72.27   58     2.25    30.0    0.00
       70     GF1     22.14    123.29   84     3.01    67.2    0.21
       90     LP1     14.53    108.75   20     0.90    26.1    0.00
      100     DF1     23.27    121.03   32     2.09    75.3    2.73
                                                                      137     17.3     32.     52.     125.6     49.0
```

Figure 8.—Tree and stand attributes table from the Prognosis Model output.

```
                    STAND GROWTH PROGNOSIS SYSTEM        VERSION 4.0 -- INLAND EMPIRE

                                  SUMMARY STATISTICS
---------------------------------------------------------------------------------------------------------
                VOLUME PER ACRE        REMOVALS PER ACRE               AVE    GROWTH
              -----------------  -----------------------  BA/         DOM  ----------- STAND    IDENTIFIERS
         TREES TOTAL MERCH MERCH TREES TOTAL MERCH MERCH ACRE         HT   PRD ACC MOR SAMPLE  -------------
YEAR AGE /ACRE CU FT CU FT BD FT /ACRE CU FT CU FT BD FT SQFT  CCF  FT   YRS CUFT/YR WEIGHT  STAND    MGMT
---- --- ----- ----- ----- ----- ----- ----- ----- ----- ---- ---  ---  --- --- --- ------  -------- ----
1977  57   536  1541  1075  2804   296   290   250   645   64  84   64   10  82   8      11  S248112 NONE
1987  67   223  1991  1627  4645     0     0     0     0   89 112   71   10 106  12      11  S248112 NONE
1997  77   209  2934  2648  9128     0     0     0     0  115 139   77   10 114  18      11  S248112 NONE
2007  87   196  3887  3606 14518    39   945   895  3765  108 131   81   10 128  19      11  S248112 NONE
2017  97   148  4032  3829 16871     0     0     0     0  132 151   88   10 136  26      11  S248112 NONE
2027 107   139  5126  4914 23122     0     0     0     0  152 169   91   10 157  34      11  S248112 NONE
2037 117   131  6351  6127 29948    96  4846  4676 23273   40  40  113   10  33   7      11  S248112 NONE
2047 127    33  1760  1703  8034     0     0     0     0   44  43  119   10  51   9      11  S248112 NONE
2057 137    32  2183  2123 10684     0     0     0     0   52  49  126    0   0   0      11  S248112 NONE


                                        ACTIVITY SUMMARY

STAND ID= S248112     MANAGEMENT ID= NONE     HYPOTHETICAL PRESCRIPTION FOR USER'S MANUAL -- NIC4 VERSION

---------------------------------------------------------------------------------------------------------

CYCLE  DATE  EXTENSION  KEYWORD    DATE  ACTIVITY DISPOSITION   PARAMETERS:
-----  ----  ---------  --------   ----  --------------------   -------------------------------------------

   1   1977
             BASE       THINPRSC   1980  DONE IN 1977                1.00

   2   1987
   3   1997

   4   2007
             BASE       SPECPREF   2010  DONE IN 2007                2.00      999.00
             BASE       SPECPREF   2010  DONE IN 2007                7.00     9999.00
             BASE       THINBTA    2010  DONE IN 2007              157.00        0.98

   5   2017
   6   2027

   7   2037
             BASE       SPECPREF   2040  DONE IN 2037                3.00     -999.00
             BASE       SPECPREF   2040  DONE IN 2037                4.00      -99.00
             BASE       THINBTA    2040  DONE IN 2037               35.00        0.98

   8   2047
---------------------------------------------------------------------------------------------------------
```

Figure 9.—Summary table from the Prognosis Model output.

The Input Summary Table

PROGRAM OPTIONS

The table displaying the options selected, the activity schedule, and the calibration statistics (fig. 6) is printed to verify that the projection is based on the intended silvicultural and ecological assumptions. These data facilitate recordkeeping and problem determination.

The keyword records are printed as they are processed. The descriptions of parameters and supplemental data are quite terse. The discussion of keyword records contained elsewhere in this manual will help resolve ambiguities.

Within this segment of the table, you may find messages such as:

SPSO3 WARNING: FOREST CODE INDICATES THAT THE GEOGRAPHIC LOCATION IS OUTSIDE THE RANGE OF THE MODEL.

These messages are intended to bring attention to potential problems with input data. Even though the messages may indicate doubt, we usually assume that you know what you are doing; the projection is continued unless program capacities have been exceeded. The possible warning messages are collected in appendix C along with explanatory details and suggested user responses.

Several keyword records will be specifically printed if they are omitted from the input file. These records contain data that are particularly useful for debugging but may not be easily remembered. They include:

(1) the tree record format (TREEFMT),
(2) the sampling design parameters (DESIGN), and
(3) the stand description data (STDINFO).

These data are printed immediately following the input keyword records, beneath the heading "OPTIONS SELECTED BY DEFAULT" (for example, TREEFMT and DESIGN in fig. 6).

The input keyword records are always displayed in the order that they are processed. Usually this order is unimportant. However, if a TREEDATA record is used and the species codes or the tree record format differ from the default specifications, the SPCODES and/or TREEFMT records must precede the TREEDATA record in the input file. Failure to meet this requirement will result in a variety of errors.

ACTIVITY SCHEDULE

The activity schedule follows the lists of options selected. The management activities that were specified by keyword input are arranged in the order that they will be simulated. The dates on the activity schedule are calculated from the inventory year, as entered on the INVYEAR record, and the intervals specified on the TIMEINT record. These dates represent projection cycle endpoints (in fig. 6, cycle 1 is the period 1977-87; cycle 2 is the period 1987-97, etc.).

CALIBRATION STATISTICS

After the keyword input is interpreted, the tree records are scanned for missing height and crown ratio observations. Then, factors that scale growth predictions to match the input growth data are computed. These activities are reported in the calibration statistics section of the input summary table (fig. 6).

The total number of tree records excludes records that were rejected because *DBH* was not recorded. It also excludes records of those trees that died before the start of the mortality observation period (tree history codes 6 and 7). The count includes the trees that died

during the mortality observation period (tree history code 5). These recent mortality records are used to compute the stand density estimates that are used in scaling models. The number of recent mortality records is given immediately below the total tree record count (fig. 6). These records will be removed from the tree record file before the stand is projected. If either of these counts appears to be inaccurate, the tree history codes, species codes, and tree record format should be checked.

The Prognosis Model will accept records with omitted height or crown ratio observations. However, these data must be estimated before the stand can be projected. Heights are predicted from *DBH* and species. If four or more records for a species have measured heights, the parameters of the equation used for that species will be fitted to the input data. However, records with measured heights but dead or broken tops are not used. The total number of records less the number of records with missing heights and broken or dead tops gives the number of records available for calibrating the height-*DBH* relationship for a species.

The omitted crown ratio observations are estimated using a variety of stand and tree characteristics (see section titled Missing Data). Variation is introduced by drawing random errors from a Normal distribution. We strongly recommend that crown ratios for all sample trees be measured and recorded. If crown ratios and/or heights were recorded, and the output indicates they are missing, the tree record format is probably in error.

The remaining entries in the calibration statistics table refer to the process of computing growth model scale factors. If increment data are provided with the tree records, the diameter increment model and the small tree height increment model will be scaled to reflect local deviations from the regional growth trends represented in the models. In order to compute scale factors for either increment model, for any species, there must be two or more increment observations. Diameter increment observations are accepted only from trees that were 3 inches *DBH* or larger at the **start** of the growth measurement period. Height increment observations are accepted only from trees that were less than 5 inches *DBH* at the **end** of the period. The number of records that is reported as available for scaling a model includes only those records that have measured increments and meet the above size restrictions.

The height increment scale factor is used as a direct multiplier of predicted height increment. However, the diameter increment scale factor is used as a multiplier of change in squared diameter (*DDS*) and is, in effect, a multiplier of basal area increment. The rate of conversion of *DDS* to diameter increment is dependent on the magnitude of tree *DBH*.

The scale factors for both models should normally fall between 0.5 and 2.0. We have assumed that the model estimate of basal area increment derived from our extensive data base is the best available predictor of long-term growth performance. As the stand is projected through time, we move the basal area increment scale factors toward 1.0. The effect of this transition is to gradually replace sample-based estimates of increment with the model-based estimates (see appendix A).

The remaining entries in the calibration statistics table are by-products of the diameter increment scaling process. They indicate how the distribution of the growth sample compares to the distribution of our data base. The distribution variances are compared using the ratio of the standard deviation of the residuals for the growth sample to the model standard error. If the values of this ratio consistently exceed 1.0, you should carefully examine your growth measurement techniques, including the methods used to delineate stands. We assume that stands are uniform with regard to slope, aspect, elevation, and habitat type. If this assumption is stretched too far, the variance in the growth sample residuals will be exaggerated.

The final table entry is the weight given to the diameter increment sample during scaling. This weight is part of an empirical Bayes estimation process (Krutchkoff 1972) that is complex and will not be explained here. The interpretation of the weight, however, is quite simple. Values in the vicinity of zero imply that the models were not adjusted while values close

to 1.0 imply that the models were adjusted. The weight is an expression of our confidence that the growth sample represents a different population than does our model data base.

Stand Composition

One line in the stand composition table is allotted to the description of each reported stand attribute at each cycle endpoint. The description consists of a terse label, the per-acre total for the attribute, the distribution of the attribute by *DBH* class, and the distribution of the attribute by species and tree value class. The per-acre total is located near the center of the table and separates the distribution by *DBH* (located to the left of the total) from the distribution by species and tree value class (fig. 7).

The attributes summarized in the stand composition table include trees per acre, volume per acre for three merchantability standards, and annual per-acre accretion and mortality (total stem cubic feet). The merchantability standards used to compute volumes include:

(1) Total stem cubic feet;

(2) Merchantable stem cubic feet; merchantability limits are provided by the user (default values are 1-foot stump height, 4.5-inch minimum top diameter, and 6-inch minimum *DBH* for lodgepole pine, 7-inch minimum *DBH* for other species).

(3) Merchantable stem Scribner board feet, assuming a 1-foot stump height, a 9-inch minimum *DBH*, and an 8-inch minimum top diameter.

The trees per acre and the volume per acre are reported at the beginning of the projection. These are repeated, along with accretion and mortality statistics, at the completion of each projection cycle. If there are any thinnings in a cycle, the number of trees per acre and the volume per acre removed as well as the number of trees per acre in the residual stand are reported.

By compromising traditional format, we are able to capture the essence of a stand or stock table in a single line of output. The compromise consists of defining the classes in the table as fixed percentages of the total for the attribute. Thus, the smallest class is defined as the interval between zero and the *DBH* such that 10 percent of the attribute is in trees that are the same size or smaller (0.1 in the 1977 TREES distribution, see fig. 7). This value is referred to as the 10th percentile point in the distribution of the attribute by *DBH*. We also identify the 30th, 50th, 70th, 90th, and 100th percentile points in the distributions of each of the attributes. The intervals between these percentile points define five additional classes. By abandoning fixed *DBH* classes, we are able to summarize a long-term projection in a compact table, with little loss of detail (fig. 10).

The remaining information in the stand composition table concerns the distribution of each attribute by species and tree value class. Tree value class is entered with the tree record and remains unchanged throughout the projection. This variable has a value of 1, 2, or 3 and influences the tree removal priority when the stand is thinned (see section titled Computing Removal Priority). We compute the percentage of each attribute that is distributed to each possible combination of species and tree value (there are 33 combinations). We then print the percentages for the four largest combinations.

Experience has shown that, although the stand composition table is detailed and compact, the format is somewhat formidable to the inexperienced user. We have prepared several illustrations that will help you visualize the distributions represented in the table. It is relatively easy to construct histograms that illustrate the distributions of attributes by *DBH* (fig. 11, 12, 13). The area of the rectangle representing a *DBH* class is equal to the quantity of the attribute associated with the class—either 10 or 20 percent of the total. The width of the rectangle (horizontal axis) is equal to the *DBH* interval between percentile points. For example, in the year 2007 in our sample output (see fig. 7), there are 196 trees per acre. Ten percent of these (19.6 trees per acre) are less than or equal to 7.7 inches *DBH*. Thus, the area of the rectangle representing the smallest *DBH* class is 19.6, the width is 7.7, and the height (vertical axis) is 2.55 (19.6 ÷ 7.7).

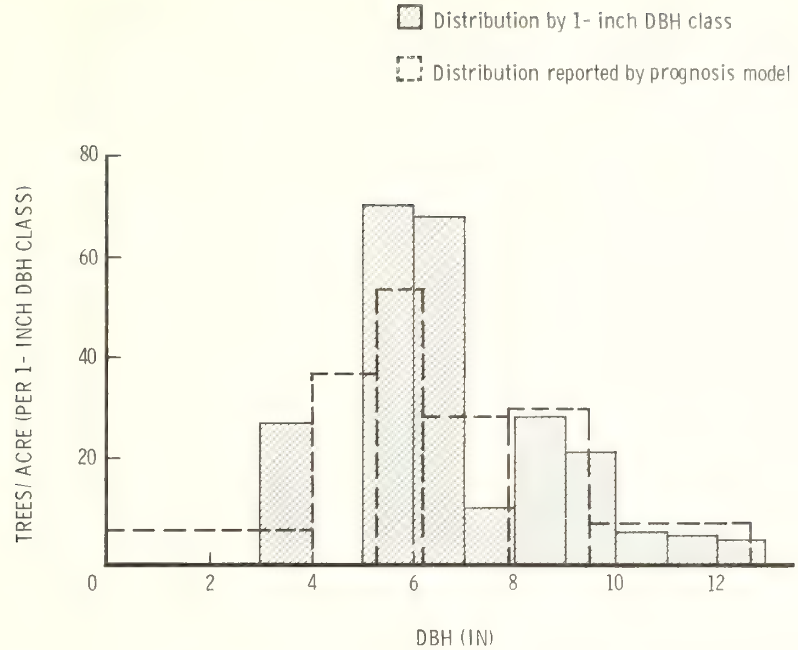


Figure 10.—The distribution of trees by *DBH*. The histogram outlined with dashes was developed from the percentile points reported by the Prognosis Model. The shaded histogram shows how the same sample of tree records is distributed by 1-inch *DBH* classes.

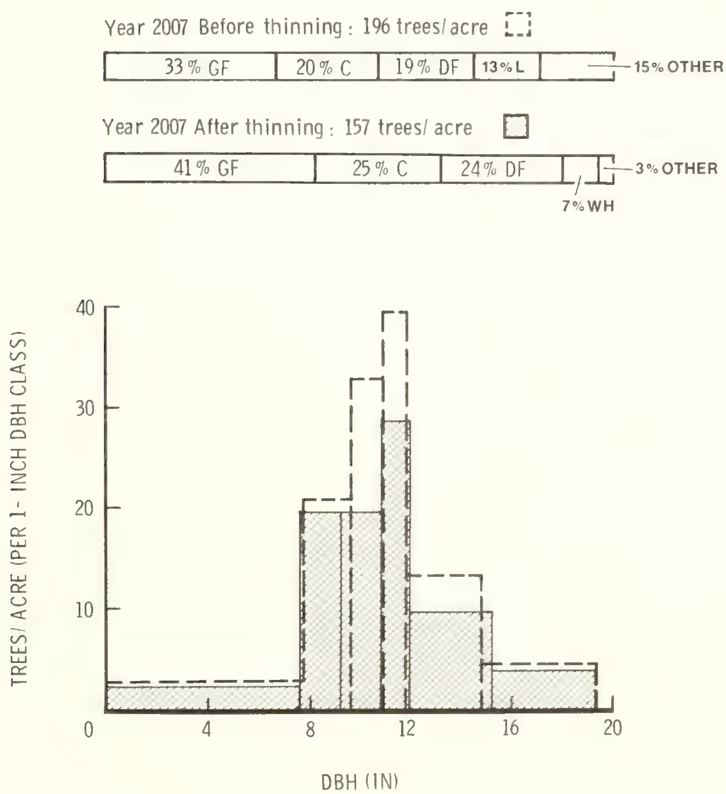


Figure 11.—Examples of before- and after-thinning distributions of trees per acre by species and by *DBH*.

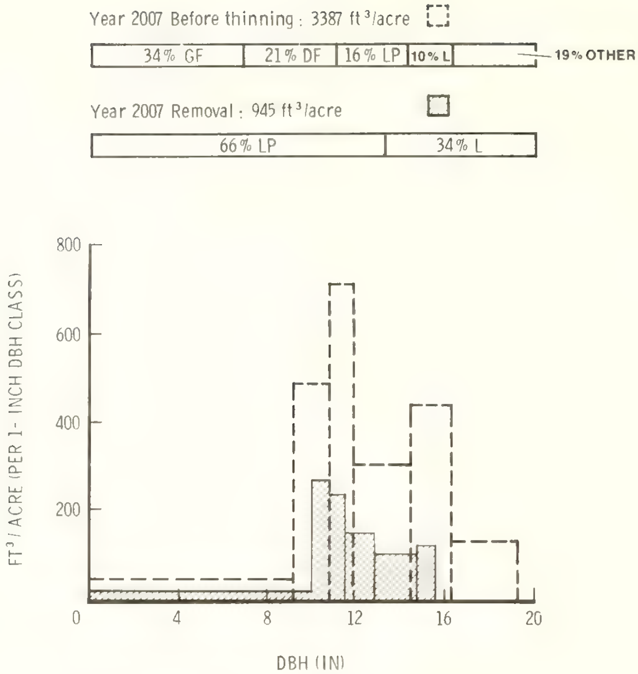


Figure 12.—Examples of distributions of total cubic volume by species and *DBH* showing the before-thinning distribution and the distribution of the removed material.

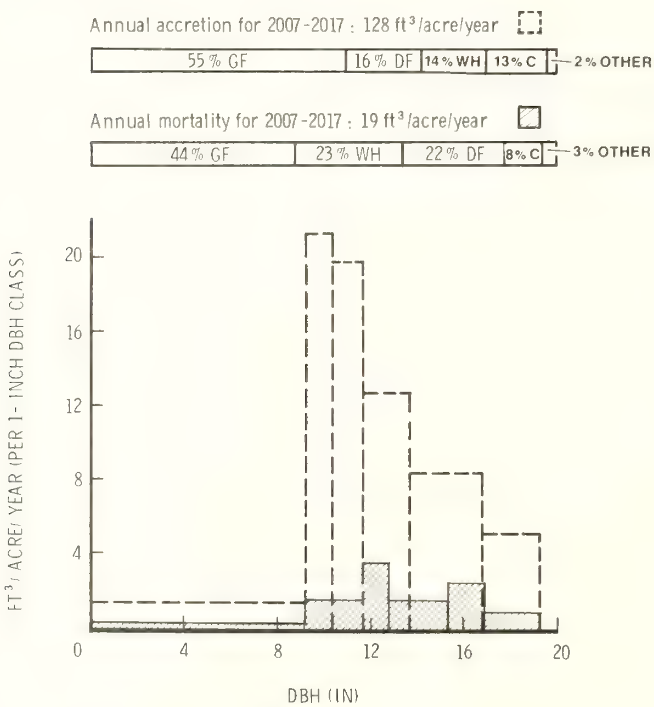


Figure 13.—Examples of distributions of accretion and mortality by species and by *DBH*.

These distributions can also be arrayed by cycle to illustrate changes in the various attributes over time (fig. 14, 15). Plotting changes in the percentile points of the distributions over time will give a snapshot of how management actions influence stand composition (fig. 16, 17). Finally, with a little arithmetic, it is possible to estimate average volume by species and plot the trend over time (fig. 18).

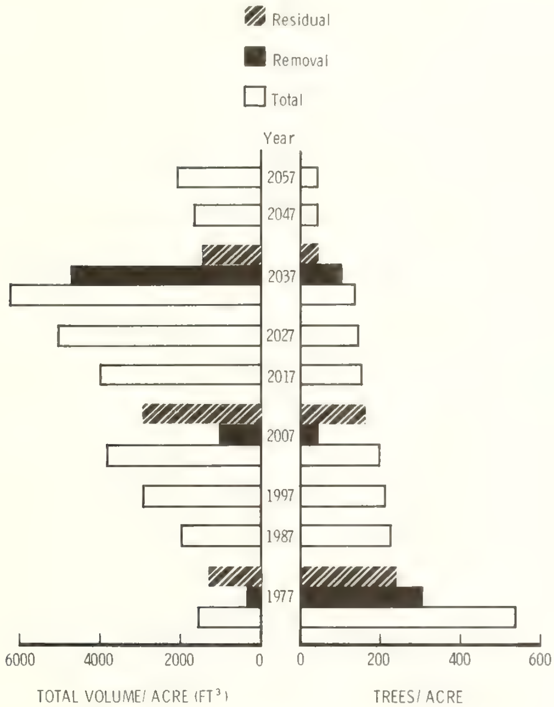


Figure 14.—Changes in total cubic volume and trees per acre over time.

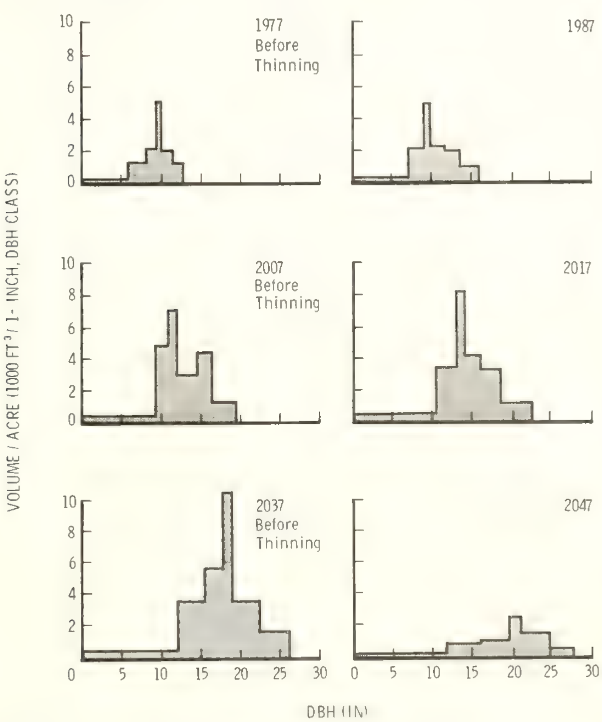


Figure 15.—Changes in the distribution of total cubic volume per acre by *DBH* through time.

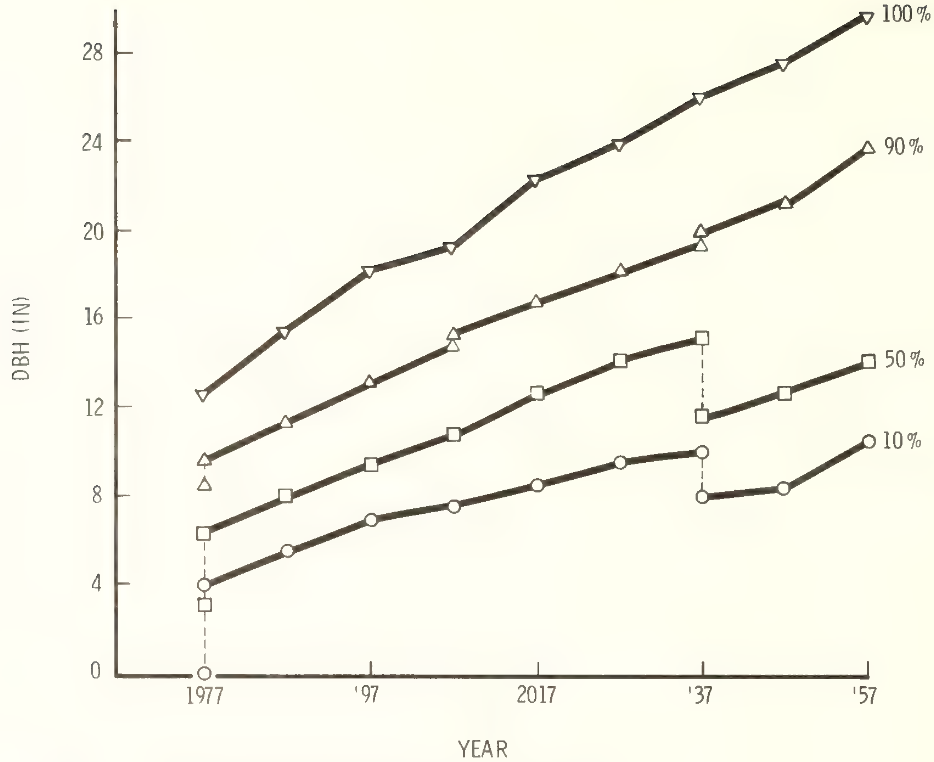


Figure 16.—Changes in the percentile points of the distribution of trees per acre by *DBH* through time. Discontinuities indicate thinning.

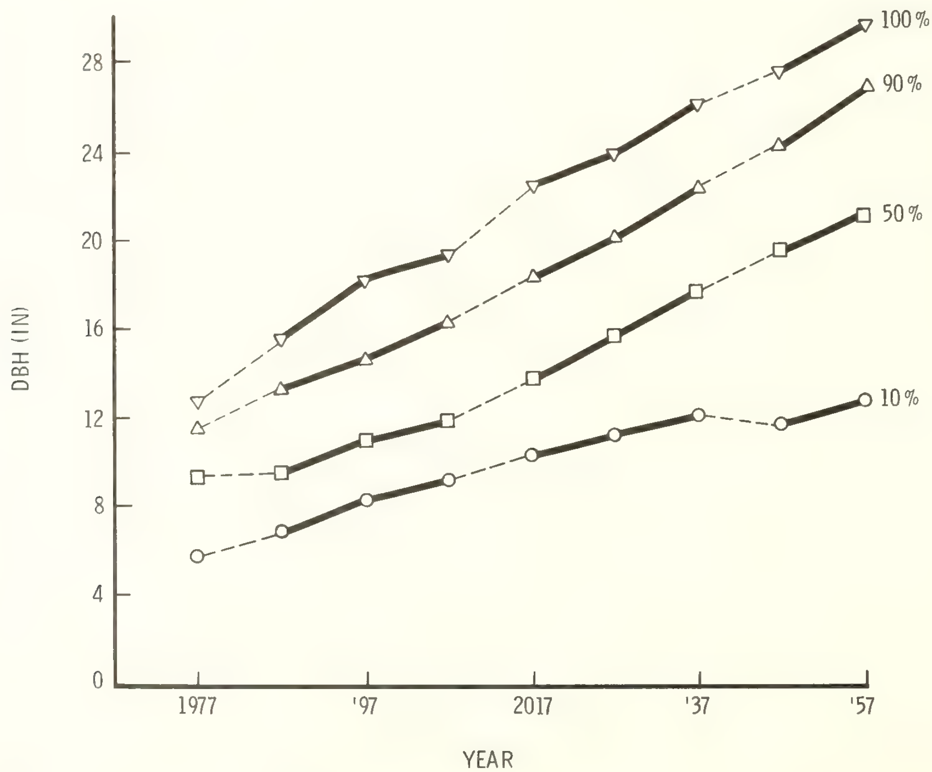


Figure 17.—Changes in the percentile points of the distribution of total cubic volume by *DBH*, over time. Dashed segments represent growth periods immediately following thinning.

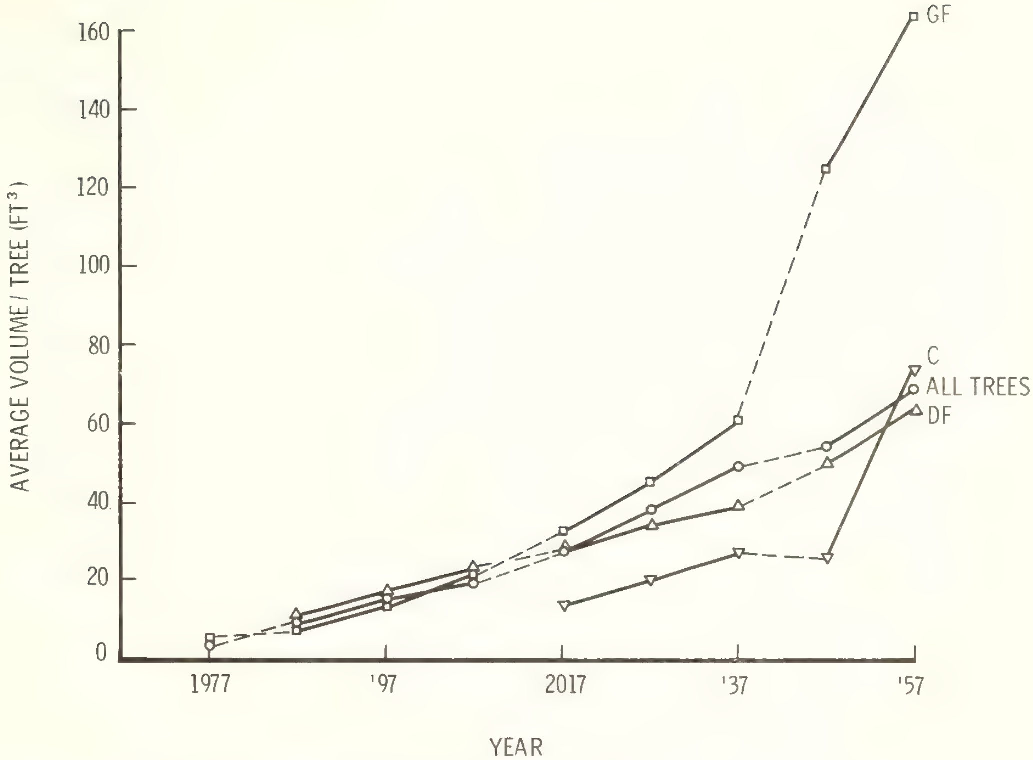


Figure 18.—Change in average volume per tree by species through time. Dashed segments indicate growth periods immediately following thinning.

Tree and Stand Attributes

The stand composition table portrays the development of the stand over time. The growth of individual trees, and the stand conditions that influence tree growth are recorded in the tree and stand attributes table (fig. 8).

The trees that are selected for display correspond to the *DBH's* recorded for the percentile points in the initial trees-per-acre distribution (the percentile points in the 1977 TREES distribution, compare fig. 7 and 8). These trees reflect a cross section of the stand and are followed throughout the projection. The initial percentile values are maintained to identify the trees. Beyond the initial report, however, these percentile values do not reflect the actual percentile position of the trees in the stand.

At the beginning of the projection, and at the end of each cycle, the following attributes are displayed for the selected trees:

- Species and tree value class.
- Current *DBH* outside bark.
- Current height.
- Live crown ratio (expressed as a percent of total height).
- Inside bark *DBH* increment for the preceding projection cycle.
- Percentile in the stand basal area distribution.
- Number of trees per acre represented by the record.

The stand attributes reported are stand age, stand density, and average tree size. Density is indicated by trees per acre, basal area per acre, and crown competition factor. Average tree size is reported as quadratic mean *DBH* (the *DBH* of the tree of average basal area) and the average height of dominants. The average height of dominants is computed by averaging the heights of all trees in the upper 30th percentile of the stand basal area distribution. When the stand is thinned at the start of a cycle, stand attributes are repeated to reflect the impact of thinning.

The information presented in the tree and stand attributes table gives additional insight into the course of stand development (fig. 19). It also reflects how a cross section of trees in the stand responds to changes in stand structure (fig. 20).

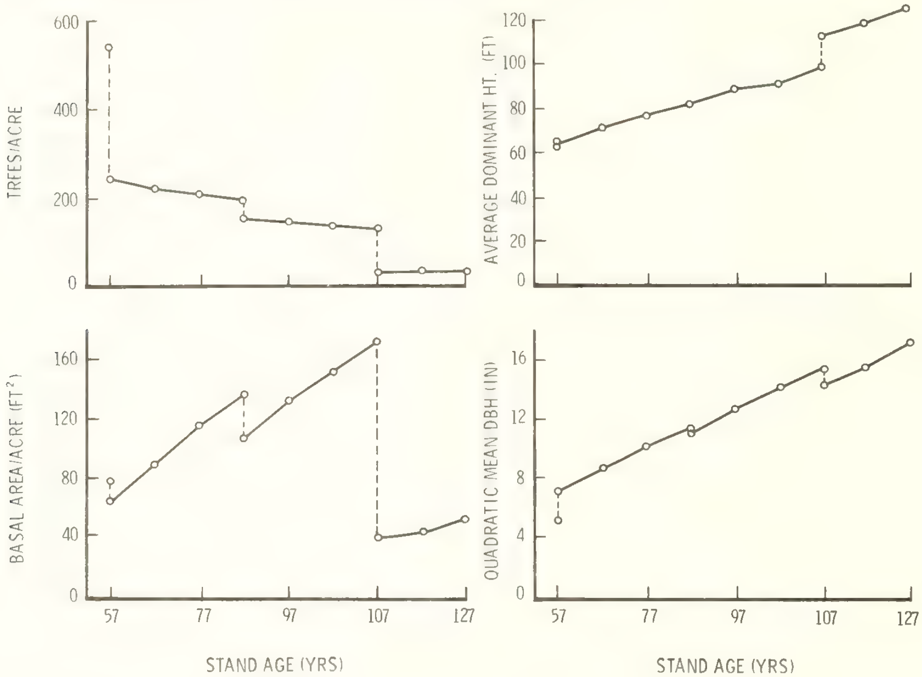


Figure 19.—Changes in stand attributes over time. Discontinuities indicate thinning.

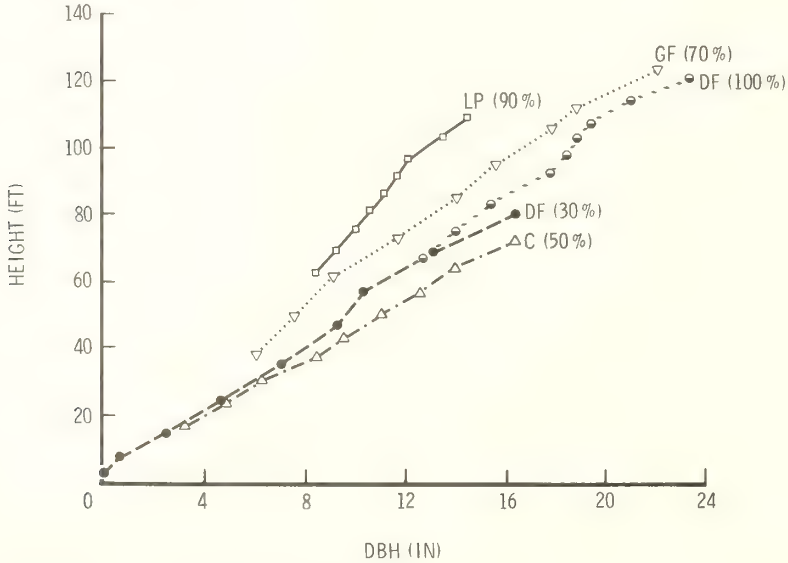


Figure 20.—Tree height versus *DBH* for four different species through time. The percentage values indicate the initial percentile of the tree in the distribution of trees per acre by *DBH*.

The Summary Table

Many of the stand attributes are repeated, in concise format, in the summary table (fig. 9). A single line in the table summarizes stand conditions at each cycle endpoint. This output was initially intended to reproduce yield data for subsequent machine processing. As a result, there are three fields in each record in which the program inserts user-supplied labels for the output: the sample weight, a stand identification, and a management identifier consisting of a four-character label (see section titled ENTERING STAND AND TREE DATA). In addition, the summary table reports per-acre trees and volume before thinning (to three merchantability standards), per-acre trees and volume removed, basal area per acre after thinning, crown competition factor (*CCF*), average dominant height, and growth period length, accretion, and mortality (the last two in total cubic feet per acre per year).

Additional Output and Keywords

Several additional outputs may be specifically requested. The first is a complete list of all tree records (fig. 21) that can be generated in any or all cycles with the TREELIST record. The tree list reports all of the tree attributes given in the tree and stand attributes table. In addition, it gives past periodic height increment, total cubic foot volume, board foot volume (corrected for form and defect), normal height, and truncated height. These last two variables reflect the status of trees with dead or missing tops and have a value of zero for trees without top damage. To generate this list use:

TREELIST field 1: The cycle in which a complete list of trees is to be printed. The list is printed at the end of the cycle and the records are updated to include growth for the period. If blank, a tree list will be generated at the beginning of the projection and at the end of each cycle. This option usually generates a lot of extra output

COMPLETE TREE LIST -- STAND: S248112 MGMTID: NONE END CYCLE: 1 YEAR: 1987 PAGE: 1

TREE NUM	SPE CODE	TREES PER ACRE	CURRENT DIAMETER	DIAMETER INCREMENT	CURRENT HEIGHT	HEIGHT INCREMENT	CROWN RATIO	BASAL AREA PERCENTILE	TREE CLASS	TOTAL CU FT VOL.	NET BOARD FT VOL.	NORMAL HEIGHT	TRUNCATED HEIGHT
34	2	2.4990	9.53	1.389	88.80	13.802	26	63.015	1	14.85	50.66	0	0
4	2	5.9977	8.68	0.668	86.77	11.775	23	40.990	1	12.04	0.0	0	0
35	2	1.4994	8.27	0.315	85.19	10.193	23	33.454	1	10.72	0.0	0	0
36	2	0.0024	9.62	1.377	76.62	13.620	24	63.017	2	13.54	47.70	8618	5600
5	2	0.0059	8.78	0.661	74.53	11.528	23	40.993	2	11.11	0.0	8409	5600
37	2	0.0015	8.37	0.312	72.90	9.898	23	35.778	2	9.97	0.0	8246	5600
40	2	2.2154	10.21	1.543	13.36	8.363	5	67.067	1	2.56	0.0	0	0
7	2	5.3170	9.27	0.744	11.90	6.899	5	52.462	1	1.88	0.0	0	0
41	2	1.3293	8.81	0.351	10.75	5.754	5	41.624	1	1.54	0.0	0	0
46	2	2.3227	10.23	1.726	79.23	14.230	45	68.551	1	15.25	52.84	0	0
10	2	5.5745	9.18	0.837	76.93	11.925	43	47.512	1	11.94	34.89	0	0
47	2	1.3936	8.67	0.396	75.11	10.113	43	38.226	1	10.38	0.0	0	0
30	3	0.0184	0.97	0.754	7.39	5.392	55	0.000	2	0.04	0.0	0	0
2	3	0.0442	0.65	0.479	7.39	5.392	55	0.000	2	[illegible]	0.0	0	0
31	3	0.0110	0.44	0.299	7.39	5.392	55	0.000	2	0.02	0.0	0	0
44	3	6.2943	6.72	2.358	33.59	13.589	24	10.388	1	3.47	0.0	0	0
9	3	15.1063	5.34	1.161	32.78	12.775	19	3.133	1	2.28	0.0	0	0
45	3	3.7766	4.63	0.547	32.11	12.115	20	0.498	1	1.76	0.0	0	0
48	3	0.0062	4.94	3.238	21.50	10.495	60	0.501	2	1.31	0.0	0	0
11	3	0.0148	3.31	1.829	21.50	10.495	54	0.002	2	0.68	0.0	0	0
49	3	0.0037	2.32	0.975	21.50	10.495	55	0.001	2	0.39	0.0	0	0
50	3	0.0062	5.65	3.247	24.20	11.203	53	3.825	2	1.85	0.0	0	0
12	3	0.0149	3.92	1.747	24.20	11.203	44	0.003	2	1.00	0.0	0	0
51	3	0.0037	2.92	0.885	24.20	11.203	45	0.001	2	0.63	0.0	0	0
56	3	1.5938	12.80	2.424	77.30	12.300	35	92.318	1	25.51	101.61	0	0
15	3	3.8250	11.32	1.142	74.42	9.424	33	79.265	1	19.59	70.27	0	0
57	3	0.9563	10.60	0.523	72.18	7.176	33	71.938	1	16.86	56.05	0	0
60	3	0.9869	15.45	2.388	77.99	10.992	34	100.000	1	36.59	161.51	0	0
17	3	2.3684	13.98	1.110	75.40	8.396	33	98.560	1	29.33	122.48	0	0
61	3	0.5921	13.28	0.504	73.39	6.389	33	92.956	1	25.96	[illegible]	0	0
64	3	0.0015	13.59	2.768	67.73	12.732	44	94.241	2	24.19	102.65	6906	4900
19	3	0.0035	11.91	1.312	64.77	9.771	43	79.908	2	18.37	68.75	6610	4900
65	3	0.0009	11.09	0.602	62.44	7.444	43	76.270	2	15.70	53.40	6377	4900
70	3	1.7986	12.16	2.391	73.20	13.195	35	[illegible]	1	21.98	83.18	0	0
22	3	4.3167	11.70	1.129	70.47	10.473	34	74.959	1	16.75	55.64	0	0
71	3	1.0792	10.00	0.518	68.34	8.339	33	[illegible]	1	14.35	43.17	0	0
38	4	4.0137	8.59	2.185	50.57	12.573	47	37.587	1	8.73	0.0	0	0
6	4	9.6329	7.36	1.063	49.22	[illegible]	44	21.339	1	6.24	0.0	0	0
39	4	2.4082	6.75	0.502	48.15	10.150	43	[illegible]	1	5.13	0.0	0	0
52	4	0.0184	0.95	0.780	8.69	5.692	65	0.000	2	0.02	0.0	0	0
13	4	0.0442	0.63	0.488	8.69	5.692	65	0.000	2	[illegible]	0.0	0	0
53	4	0.0110	0.42	0.297	8.69	5.692	65	0.000	2	0.00	0.0	0	0
54	4	5.4708	8.34	2.779	39.00	11.999	69	35.778	1	6.34	0.0	0	0
14	4	13.1300	6.81	1.379	37.95	10.946	64	14.776	1	4.11	0.0	0	0
55	4	3.2825	6.02	0.659	37.10	10.096	63	4.552	1	[illegible]	0.0	0	0
58	4	4.1446	9.23	2.861	51.18	13.181	75	49.668	1	10.19	22.21	0	0
16	4	9.9469	7.65	1.417	49.76	11.759	75	28.690	1	6.81	0.0	0	0
59	4	2.4867	6.84	0.677	48.61	10.612	74	15.487	1	5.32	0.0	0	0
68	4	1.3188	13.00	2.470	77.50	12.500	66	95.731	1	[illegible]	151.20	0	0
21	4	3.1651	12.20	1.186	74.64	9.639	65	88.034	1	25.98	109.42	0	0
69	4	0.7913	11.51	0.555	72.39	7.395	64	79.905	1	[illegible]	89.81	0	0
80	4	3.5481	9.46	2.621	42.25	12.249	68	61.628	1	8.86	14.80	0	0
27	4	8.5154	8.01	1.288	40.73	10.728	64	32.828	1	6.11	0.0	0	0
81	4	2.1289	7.27	0.611	39.51	9.510	63	18.147	1	4.88	0.0	0	0
32	5	3.4419	11.95	5.087	42.82	12.825	80	82.910	1	13.39	36.22	0	0
3	5	8.2607	9.40	2.707	41.36	11.364	77	59.686	1	8.00	6.63	0	0

Figure 21.—Example of complete tree list output from the Prognosis Model.

The second optional output is a copy of the summary table routed without headings to a supplemental output unit. This unit can be referenced to a tape or disk drive, producing a machine readable copy of the yield table resulting from the projection. The copy of the summary table is requested with the ECHOSUM record:

ECHOSUM field 1: Dataset reference number for output of summary table copy; default = 4.

When using the ECHOSUM option to produce a machine readable copy of the summary table, a four-character label can be added (see fig. 9, identifiers) to assist subsequent processing. The label is entered with the MGMTID record (see section titled Identifying the Stand).

Finally, explanatory text may be added to the output to aid in interpretation. To enter this text, the COMMENT and END records are needed. These keywords define the beginning and end of a set of text that will be reproduced, verbatim, in the input summary table. There are no restrictions on the number or format of records used to input comments except that the first three columns cannot contain the word "END" if the fourth column is blank. **Note**: if END is omitted from the keyword file, subsequent keyword records will be treated as part of the COMMENT packet, and the projection likely will fail.

For example, a description of silvicultural objectives could be added to the output for the simulation of our example prescription:

```
COMMENT
  THE PRESCRIPTION CALLS FOR IMMEDIATE REMOVAL OF
  EXCESS TREES, A COMMERCIAL THINNING AT AGE 90
  TO REMOVE LODGEPOLE AND LARCH, A SHELTERWOOD
  REGENERATION TREATMENT AT AGE 120 FAVORING
  GRAND FIR AND DOUGLAS-FIR, AND AN OVERWOOD
  REMOVAL AT AGE 130.
END
```

INSIDE THE PROGRAM

Information presented in previous sections of this manual will enable you to prepare input for a Prognosis Model projection and interpret the resulting output. The Prognosis Model is, however, more than a computer program. It is a set of mathematical models that represent tree and stand development. A basic understanding of these models is essential to effective program use. For this reason, we have included the following "guided tour" through the various equations and operations that lead to each stand projection.

Getting Started

The initial phase of our tour considers the beginning of the projection. We first read and interpret any user instructions and all inventory records. These processes were described in the previous sections, and we will assume for now that they have been successfully completed. Before the actual projection can begin, however, several housekeeping chores must be performed.

BACKDATING INPUT DIAMETERS

The Prognosis Model uses a forward-projection technique. The predictions of growth are dependent on the tree and stand conditions at the start of the growth period. When current diameter breast height (*DBH*) and past periodic increment (*DG*) are entered, diameters must be backdated before growth models are calibrated. In the model, *DBH* is assumed to

be measured outside bark while increment is assumed to be measured inside bark. In order to backdate diameters properly, an adjustment is made to correct for bark growth (Monserud 1979). The adjustment is of the form

$$DBH_0 = DBH - k \cdot DG$$

where DBH_0 is the diameter outside bark at the start of the growth period and k is a species-specific bark growth adjustment factor (table 7).

Stand density statistics are compiled using tree diameters and, therefore, all diameters must be backdated even though increments are not measured on all trees. In order to backdate trees without measured diameter increments, we compute the basal area ratio:

$$BAR = \frac{DBH_0^2}{DBH^2}$$

for all trees with measured increments. The values of BAR are averaged by species, and the average ratios are applied to trees with missing increments

$$DBH_0 = \sqrt{BAR \cdot DBH^2}$$

When none of the trees for a species have measured increments, BAR is assumed to be equal to 1.0.

STAND DENSITY STATISTICS

Three stand density descriptors are used by the Prognosis Model. These descriptors are basal area per acre, crown competition factor (*CCF*), and the basal area percentile distribution. Before density statistics can be computed, the number of trees per acre (*PROB*) associated with each tree record must be determined. *PROB* is a function of tree *DBH* and the sampling design parameters (see section titled Describing the Stand). For fixed area plots,

$$PROB = \frac{1}{N \cdot A}$$

For variable radius plots,

$$PROB = \frac{BAF}{0.005454 \cdot N \cdot DBH^2}$$

where

N = number of sample plots in the stand
A = area of a sample plot (acres)
BAF = basal area factor for horizontal angle guage (ft^2/acre/tree)

Table 7.— Bark growth adjustment factors and sources. These factors are used to predict total increment (bark and wood) given only the wood increment

Species	Adjustment factor	Source
Western white pine	1.037	Fince (1948)
Western larch	1.175	Finch (1948)
Douglas-fir	1.153	Monserud (1979)
Grand fir	1.093	Finch (1948)
Western hemlock	1.071	Finch (1948)
Western redcedar	1.053	Finch (1948)
Lodgepole pine	1.032	Finch (1948)
Engelmann spruce	1.047	Spada (1960)
Subalpine fir	1.063	Finch (1948)
Ponderosa pine	1.128	Johnson (1956)[1]
Mountain hemlock	1.053[2]	

[1]Johnson gave one factor based on 123 trees with *DBH* less than 9.5 inches (1.245) and a second factor (1.121) based on 1,951 trees with *DBH* greater than 8.5 inches. The rate we use is the weighted average of these numbers.
[2]No data were available for mountain hemlock. The rate for western redcedar is used.

When the density statistics are backdated, the *PROB*s for recent mortality records (tree history code 5) are multiplied by the ratio of diameter increment measurement period length to mortality observation period length. Periodic growth of recent mortality records is assumed to be zero. These records will be culled from the tree record file when program initialization is completed.

To compute basal area per acre, we simply sum the product of trees per acre and tree basal area across all tree records.

Crown competition factor (Krajicek and others 1961) is a relative measurement of stand density that is also based on tree diameters. Tree values of *CCF* estimate the percentage of an acre that would be covered by the tree's crown if the tree were open grown. Stand *CCF* is the summation of individual tree (CCF_t) values. A value of 100 theoretically indicates that tree crowns will just touch in an unthinned, evenly spaced stand. CCF_t is estimated from tree diameter as follows:

$$CCF_t = \begin{cases} PROB \cdot (a_0 + a_1 \cdot DBH + a_2 \cdot DBH^2) & \text{for } DBH \geq 10 \text{ in.} \\ PROB \cdot b_0 DBH^{b_1} & \text{for } DBH < 10 \text{ in.} \end{cases} \qquad (5)$$

where

a_0, a_1, a_2, b_0, b_1, are species-dependent constants (table 8).

Table 8.— Coefficients for computing the contribution of each tree record to the stand estimate of crown competition factor from tree diameter (*DBH*) (see eq. 5)

Species	Model coefficients				
	DBH < 10 inches		*DBH* ≥ 10 inches		
	b_0	b_1	a_0	a_1	a_2
Western white pine	0.00988	1.6667	0.03	0.0167	0.00230
Western larch	.00724	1.8182	.02	.0148	.00338
Douglas-fir	.01730	1.5571	.11	.0333	.00259
Grand fir	.01525	1.7333	.04	.0270	.00405
Western hemlock	.01111	1.7250	.03	.0215	.00363
Western redcedar	.00892	1.7800	.03	.0238	.00490
Lodgepole pine	.00919	1.7600	.02	.0168	.00325
Engelmann spruce	.00788	1.7360	.03	.0173	.00259
Subalpine fir	.01140	1.7560	.03	.0216	.00405
Ponderosa pine	.00781	1.7680	.03	.0180	.00281
Mountain hemlock	.01111	1.7250	.03	.0215	.00363

The basal area percentile distribution is a measure of the relative size of the trees in the stand (Stage 1973b) and, to some extent, it indicates the competitive status of each tree. The basal area percentile rank of a tree (*PCT*) is the percentage of total stand basal area represented by that tree and all trees that are the same size or smaller. The largest tree in the stand has a *PCT* of 100 and successively smaller trees have successively smaller rankings. All trees must have *PCT* greater than zero (*PCT* is listed for six of the trees in S248112 in figure 8—the tree and stand attributes output table).

MISSING DATA

We indicated earlier that tree heights and crown ratios could be subsampled. When tree heights are missing, a height-diameter function is used to estimate the missing values (fig. 22):

$$HT = \exp\left[C_0 + C_1 \cdot 1/(DBH + 1)\right] + 4.5 \qquad (6)$$

where C_0 and C_1 are species-dependent constants (table 9). When there are four or more tree records for a species with measured heights and undamaged tops, the coefficients for the height-diameter model for that species are estimated from the input data. Four trees are an adequate sample only if the trees are undamaged and they represent the entire range of *DBH* in the stand.

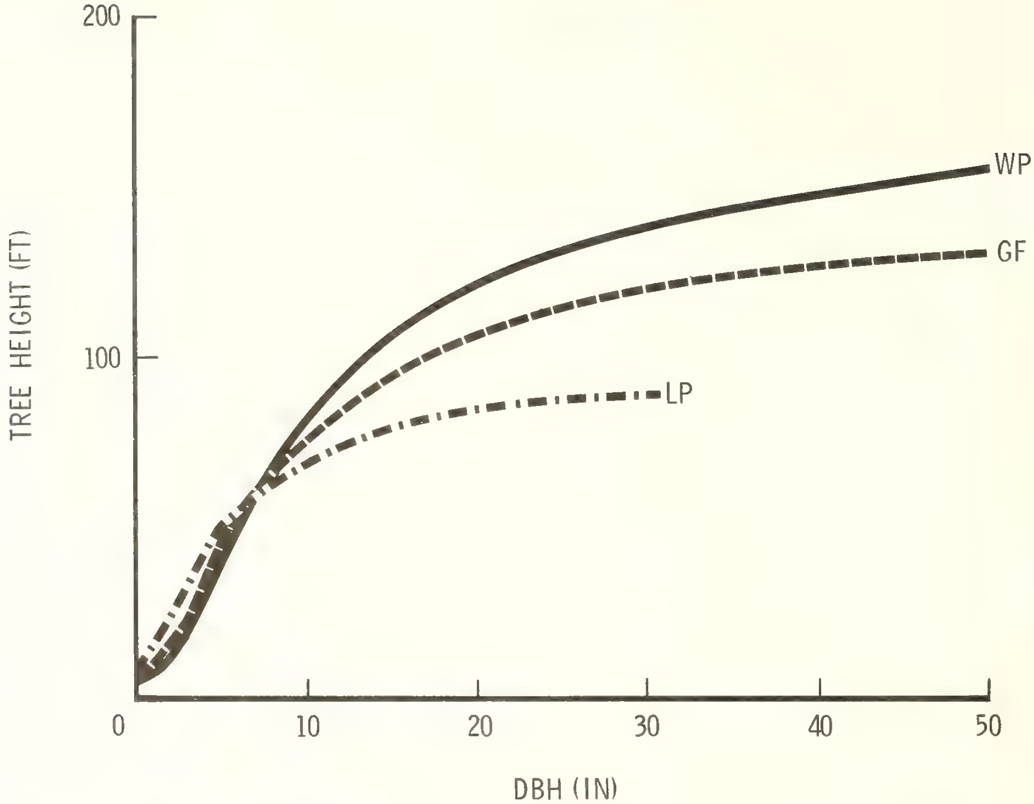


Figure 22.—Height as predicted from *DBH* with the default height-diameter equations in the Prognosis Model. The three species represented are western white pine (WP), grand fir (GF), and lodgepole pine (LP).

Table 9.—Coefficients for the default height-diameter model (see eq. 6)

Species	C_0	C_1
Western white pine	5.19988	−9.26718
Western larch	4.97407	−6.78347
Douglas-fir	4.81519	−7.29306
Grand fir	5.00233	−8.19365
Western hemlock	4.97331	−8.19730
Western redcedar	4.89564	−8.39057
Lodgepole pine	4.62171	−5.32481
Engelmann spruce	4.92190	−8.30289
Subalpine fir	4.76537	−7.61062
Ponderosa pine	4.92880	−9.32795
Mountain hemlock	4.77951	−9.31743

The missing crown ratios are estimated as a function of habitat type, *DBH*, *HT*, *PCT*, *CCF*, and species. This model is part of the algorithm we use to predict change in crown ratio and will be specified in detail when the prediction of change in crown ratio is discussed. The crown ratio model predicts an expected value. When using the model to supply missing data, a random deviate is added to the prediction. This deviate is drawn from a Normal distribution with a mean of zero and a variance of 159. This distribution approximates the distribution of residuals about the fitted model.

CALCULATION OF MODEL SCALE FACTORS TO REPRESENT INCREMENT DATA

When periodic increment data is provided to the Prognosis Model, the imbedded increment models will be adjusted to reflect local conditions. Both the diameter increment model and the small-tree height increment model may be calibrated. In both cases, the calibration factor is a multiplier that is a weighted average between the median ratio of observed to predicted values and 1.0. The weight is dependent on how closely the variation in the residuals for the stand being calibrated matches the variation in the residuals for the overall model (Stage 1973b, 1981). In a later section, we will elaborate on the calculation and use of correction factors.

Predicting Periodic Increment

When calibration is completed, stand density statistics are updated to correspond to the beginning of the first projection period. Then, the Prognosis Model prepares the input summary table (fig. 6) and the entries in other tables (figs. 7,8,9) that summarize initial conditions. Next, all scheduled thinnings are simulated and stand density statistics are again modified to reflect removals. Finally, we begin the process of projecting stand development.

Stand development is simulated by predicting increments in the dimensions of the trees that comprise the stand. The first and most important prediction is diameter increment.

DIAMETER INCREMENT PREDICTION

All facets of predicted tree development are dependent in part on diameter or diameter increment. The behavior of the Prognosis Model as a whole is, therefore, strongly influenced by the behavior of the diameter increment model and the subsequent use of *DBH* and diameter increment in the prediction of other tree attributes. Consequently, we will spend some time examining the diameter increment model and important interactions with other variables.

Specifying the Model

Actually, we do not predict diameter increment. Rather, we derive diameter increment from predicted periodic change in squared inside-bark diameter (*dds*) (Stage 1973b; Cole and Stage 1972):

$$\begin{aligned} dds &= (dib + DG)^2 - dib^2 \\ &= 2 \cdot dib \cdot DG + DG^2 \end{aligned}$$

where:

DG = periodic increment in inside bark diameter

dib = inside bark diameter at the beginning of the growth period
$= (1/k) \cdot DBH$ where k is a species dependent bark adjustment factor is given in table 7.

From the above:

$$DG = \sqrt{dib^2 + dds} - dib \qquad (7)$$

As we are primarily interested in diameter increment, we will not belabor this transformation beyond a brief explanation. The choice of dependent variable is a matter of statistical convenience: the trend in ln(*dds*) relative to ln(*DBH*) is linear and the residuals on this scale have a nearly homogeneous variance. These conclusions are based on about 45,000 data points[8] and are consistent across all species represented in the Inland Empire version.

[8]The diameter increment data used to develop this model were extracted from the inventories (1971-75) for the National Forests listed in table 2.

The diameter increment model is specified as follows:

$$\ln(dds) = HAB + LOC$$
$$+ b_1 \cdot \cos(ASP) \cdot SL + b_2 \cdot \sin(ASP) \cdot SL + b_3 \cdot SL + b_4 \cdot SL^2$$
$$+ b_5 \cdot EL + b_6 \cdot EL^2 + b_7 \cdot (CCF/100)$$
$$+ b_8 \cdot \ln(DBH) + b_9 \cdot CR + b_{10} \cdot CR^2 + b_{11} \cdot (BAL/100)$$
$$+ b_{12} \cdot DBH^2 \tag{8}$$

where:

HAB = a constant term (intercept) that is dependent on habitat type (tables 10 and 11).
LOC = a constant term (intercept) that is dependent on location (tables 10 and 12).
ASP = stand aspect (degrees).
SL = stand slope ratio (percent/100).
EL = stand elevation (in hundreds of feet).
CCF = stand crown competition factor.
CR = ratio of crown length to total tree height.
BAL = total basal area per acre in trees that are larger than the subject tree (the tree for which a prediction is being made).

b_1 through b_{12} = regression coefficients that are dependent on species (see table 10); b_{12} is dependent on location as well (table 13).

Table 10.— Coefficients of the diameter increment model by species (see eq. 8)

Variables (classes)		Species[1]										
		WP	L	DF	GF	WH	C	LP	S	AF	PP	MH
	1	0.52413	0.09942	−0.14504	−0.29300	−0.04936	−.05206	0.12576	−1.00547	−1.22567	0.51095	−1.85096
HABITAT	2	.21955	.16062	−.08077	−.18647		.11324	.43686	−.94485	−.98325	.18432	−1.70123
CLASS	3	.39811	.24828	−.01849	−.52237		−.13744	.49842	−.74478	−.81103	.37804	
INTERCEPTS	4		.20583	−.45104	−.33345			.36061	−1.43486	−1.07653	−.01902	
(HAB)[2]	5		.45896	−.21060				.18277	−1.29358	−1.50160	.28779	
	6		−.00942					.30146	−1.10471	−1.39603		
	1	.15050	.28070	.55791	.45526	.10409	.48022	.44873	.27427	.39372	.27234	.11650
LOCATION	2	.25383	.15733	.32382	.25827	.50090	.19002	.21252	.07059	.11026	.62851	.47050
CLASS	3	.0	.09762	.20639	−.21506	.0	.30175	.13555	−.14313	−.16460	.42701	.0
INTERCEPTS	4		.43740	.67618	.18436		.0	.0	.0	−.03889	.0	
(*LOC*)[3]	5		.0	.0	.58661					.0		
	6				.0							
COS(ASP) · SL	(b_1)	−.02384	−.18391	−.05446	−.04167	.10295	−.06283	.00419	−.12416	−.11696	−.10666	.18760
SIN(ASP) · SL	(b_2)	.04285	.03467	.06653	−.00710	.11043	.00762	.13073	−.05792	−.06235	.00945	.12718
SL	(b_3)	−.30352	.19829	.67627	.78498	.15025	.29811	.47800	.73989	.33983	−.00322	.09233
SL^2	(b_4)	.0	−.59316	−1.11525	−1.19852	.0	−.19797	−.62155	−.97938	−.67813	−.50149	.0
(*EL*)	(b_5)	.04126	.02672	.02187	.02059	.03200	.01269	−.00111	.06282	.06542	.03067	.08298
$(EL)^2$	(b_6)	−.000578	−.000342	−.000341	−.000260	−.000473	−.000280	−.000096	−.000711	−.000700	−.000416	−.000926
CCF/100	(b_7)	−.10407	−.10269	−.08163	−.10040	.0	−.12506	−.12417	−.10708	−.04203	−.15025	−.13803
ln (*DBH*)	(b_8)	.84748	.76815	.87807	1.04715	.85462	1.00184	.98853	.94147	.98464	.78570	1.01045
CR	(b_9)	1.13594	1.51862	2.10953	2.00814	1.84253	1.76810	1.89451	1.50962	.53338	1.07122	1.29276
CR^2	(b_{10})	.0	−.38137	−.66989	−.80903	−.49184	−.42293	−.42759	−.22132	.86079	.34044	.0
(*BAL*/100)	(b_{11})	−.37061	−.41332	−.40192	−.025244	−.34693	−.12036	−.24188	−.24366	−.22331	−.47261	−.25349
	1	−.000618	−.000495	−.000615	−.000562	−.000468	−.000176	−.001523	−.000364	−.000696	−.000475	−.000586
DBH^2	2	−.000224	−.000583	−.000724	−.000650	−.000356	−.000126	−.002498	−.000506	−.000982	−.000590	−.000381
CLASSES	3		−.000788	−.000839	−.000384	−.000593	−.000154	−.002061	−.000667	−.000459	−.000259	
(b_{12})[4]	4			−.000933	−.000867	−.000874		−.001182	−.000254			

[1]Species are defined in table 4.
[2]Habitat classes are defined in table 11.
[3]Location classes are defined in table 12.
[4]*DBH* squared classes are defined in table 13.

Table 11.—Classification of habitat effects by species among habitat types for the diameter increment model (see equation 8)

Habitat code[2]	Habitat effects by species[1]										
	WP	L	DF	GF	WH	C	LP	S	AF	PP	MH
130	3	6	5	4	1	3	6	6	6	1	2
170	3	6	5	4	1	3	6	6	6	1	2
250	3	6	5	4	1	3	6	6	6	3	2
260	3	6	5	4	1	3	6	6	6	5	2
280	3	6	5	4	1	3	1	6	6	5	2
290	3	6	5	4	1	3	2	6	6	5	2
310	3	6	5	4	1	3	3	6	6	5	2
320	3	6	1	4	1	3	6	6	6	5	2
330	3	6	5	4	1	3	6	6	6	4	2
420	3	1	5	4	1	3	6	6	6	5	2
470	3	1	5	4	1	3	6	6	6	5	2
510	3	2	1	4	1	3	2	1	6	1	2
520	1	1	2	1	1	3	2	1	1	1	2
530	1	3	3	4	1	1	4	2	2	1	2
550	1	3	3	4	1	2	4	3	3	1	2
570	1	4	3	4	1	3	4	2	4	3	2
610	1	3	3	4	1	2	4	3	3	1	2
620	1	2	3	4	1	3	4	1	1	3	2
640	3	6	5	4	1	3	5	6	6	5	2
660	3	2	4	4	1	3	5	4	6	5	2
670	2	1	2	2	1	3	4	6	6	5	1
680	2	1	2	3	1	3	5	2	6	5	2
690	3	1	5	3	1	3	6	6	6	5	2
710	3	6	5	2	1	3	6	6	6	5	2
720	3	6	5	4	1	3	6	6	6	5	2
730	3	5	5	4	1	3	5	2	1	5	2
830	3	6	4	4	1	3	5	5	5	5	2
850	3	6	4	4	1	3	6	6	6	5	2
999[3]	3	6	5	4	1	3	6	6	6	5	2

[1]Species codes are defined in table 4.
[2]Habitat codes are defined in table 3.
[3]Types grouped with 999 were included in the overall mean for the species.

Table 12.—Classification of location effects by species among National Forests for the diameter increment model (see equation 8)

National Forest	Location effects by species[1]										
	WP	L	DF	GF	WH	C	LP	S	AF	PP	MH
Bitterroot	3	1	5	6	3	4	4	4	5	1	3
Clearwater	1	1	1	1	3	1	1	1	1	2	1
Coeur d'Alene	3	2	2	2	1	1	1	1	2	2	1
Colville	3	3	3	2	3	2	2	2	2	1	3
Flathead	3	3	3	3	3	2	4	3	3	4	3
Kaniksu	3	2	2	2	3	3	3	4	3	3	3
Kootenai	3	5	3	4	3	4	3	4	4	1	3
Lolo	3	5	5	6	3	2	4	4	5	4	1
Nezperce	3	4	1	2	3	1	2	1	2	3	3
St. Joe	2	1	4	5	2	1	2	1	1	2	2

[1]Species codes are defined in table 4.

Table 13.—Classification of diameter-squared effects by species among National Forests for the diameter increment model (see equation 8)

National Forest	DBH squared effects by species[1]										
	WP	L	DF	GF	WH	C	LP	S	AF	PP	MH
Bitterroot	1	1	1	1	1	1	1	1	1	1	1
Clearwater	2	2	2	1	1	2	2	2	2	2	1
Coeur d'Alene	2	2	2	2	2	1	2	1	3	2	1
Colville	2	2	2	2	3	3	1	1	2	2	1
Flathead	1	2	3	3	1	1	1	1	3	3	1
Kaniksu	2	2	1	3	1	1	2	3	3	3	1
Kootenai	1	1	4	4	1	2	3	2	2	2	1
Lolo	1	2	1	1	1	1	1	1	1	1	2
Nezperce	1	2	1	3	1	2	4	4	3	1	1
St. Joe	2	3	4	1	4	1	1	1	2	2	2

[1]Species codes are defined in table 4.

An Example

At this point, we will demonstrate the evaluation of the diameter increment model. For an example, we will use the 19th tree record from stand S248112 (fig. 3). This tree is a Douglas-fir with a 12.7-inch DBH and a crown ratio of about 35 percent. It is the largest live tree sampled in the stand.

As previously noted, stand S248112 is located in the St. Joe National Forest on a *Tsuga heterophylla/Clintonia uniflorum* habitat type (code 570) at an elevation of about 3,400 feet. The aspect is northwesterly with about a 30 percent slope. Following a light thinning in 1977, the stand supports 64 square feet of basal area per acre and has a *CCF* of 83.8 (fig. 6,8).

For Douglas-fir, habitat type 570 is part of habitat class 3 (table 11) and the St. Joe National Forest is in location class 4 (table 12). These classes are assigned constants of −0.01849 and 0.67618, respectively (see table 10). The entire model is evaluated as follows:

—Habitat

$- 0.018$

—Location

0.676

—Slope and aspect

$= b_1 \cdot SL \cdot \cos(ASP) + b_2 \cdot SL \cdot \sin(ASP) + b_3 \cdot SL + b_4 \cdot SL^2$

$= (-0.05446) \cdot (0.3) \cdot \cos(315°) + (0.06653) \cdot (0.3) \cdot \sin(315°)$

$\quad + (0.67627) \cdot (0.3) + (-1.11525) \cdot (0.3) \cdot (0.3)$

$= 0.077$

—Elevation

$= b_5 \cdot EL + b_6 \cdot EL^2$

$= (0.02187) \cdot 34 - (0.000341) \cdot (34)^2$

$= 0.349$

—*CCF*

$= b_7 \cdot (CCF/100)$

$= (-0.08163 \cdot 0.838)$

$= -0.068$

—DBH (from table 13, the St. Joe National Forest uses the fourth DBH squared coefficient for Douglas-fir)

$= b_8 \cdot \ln(DBH) + b_{12} \cdot DBH^2$

$= (0.87807) \cdot \ln(12.7) - (0.000933) \cdot (12.7)^2$

$= 2.081$

—Crown ratio

$= b_9 \cdot CR + b_{10} \cdot CR^2$

$= (2.10953) \cdot (0.35) - (0.66989) \cdot (0.35)^2$

$= 0.656$

—Basal area in larger trees

$= b_{11} \cdot BAL$

$= (-0.40192) \cdot (0)$ (this is the largest tree in the stand)

$= 0.0$

Predicted $\ln(dds)$ is equal to 3.753 which is the sum of the above effects. Therefore,

$$dds = e^{3.753} = 42.65$$

Now to calculate diameter increment, we need the bark ratio for Douglas-fir (table 7) and equation 7:

$$DG = \sqrt{dib^2 + dds} - dib$$

$$= \sqrt{(DIB/k)^2 + dds} - (DBH/k)$$

$$= \sqrt{\left(\frac{12.7}{1.153}\right)^2 + 42.65} - \left(\frac{12.7}{1.153}\right)$$

$$= 1.79 \text{ inches}$$

The computed DG differs significantly from the increment reported in figure 8 (1.11 inches). The difference is attributable to two factors:

(1) In the example projection, the predicted growth was scaled (scale factor = 0.65; see figure 6) to reflect input increment data. We have neglected this step.

(2) Also in the example projection, the predicted growth was modified, through record tripling, to introduce some variation.

When the scale factor is applied,

$$dds = (42.65) \cdot (0.65) = 27.72$$

and the prediction of DG is reduced to 1.19 inches.

The effect of record tripling is not as easily traced. The record tripling procedure generates three records (triples) from each original record. The trees-per-acre represented in the original record are partitioned by arbitrarily assigning 25 percent to one triple (fast-growing trees), 15 percent to another triple (slow-growing trees), and 60 percent to the final triple (average-growing trees) (Stage 1973b). Each triple is then assigned an increment based on the distribution of errors about predicted increments. These errors are assumed to be distributed Normally (on the logarithmic scale), with a mean of zero and a variance equal to the weighted average of the mean squared errors from the regression model and from the input increment data (appendix A). The slow-growing trees are assigned an increment cor-

responding to the 7.5th percentile point in the distribution of errors (this is the median of the lower 15 percent). Increments assigned to the averge and fast-growing trees correspond to the 45th and the 87.5th percentile points in the error distribution, respectively. The weighted average increment prediction for the three triples is equal to the original prediction. The increments displayed in the stand and tree attributes table (fig. 8), however, are always from the middle triple and are always slightly less than the original predicted value. In the case of our example,

$$dds = 25.53,$$

resulting in a DG equal to 1.11 inches. Note, however, that the ratio of the dds associated with the 45th percentile point to the original dds prediction (in our example this ratio is 0.921) varies by species and by the distribution of the input increment data.

Behavior of Predicted Diameter Increment Relative to *DBH*

The value of *dds* is directly proportional to basal area increment. The shape of the *dds* curve relative to *DBH* is unimodal with a maximum at or beyond 20 inches *DBH*. The *DBH* at culmination of *dds* varies by species but is considerably larger than the *DBH* at culmination of diameter increment (fig. 23).

When scale factors are used to adjust for local variation in growth, the value of *dds* is directly multiplied so that there is no shift in the *DBH* at culmination of *dds*. However, as the value of the scale factor increases, the value of *DBH* corresponding to the culmination of *DG* also increases (fig. 24).

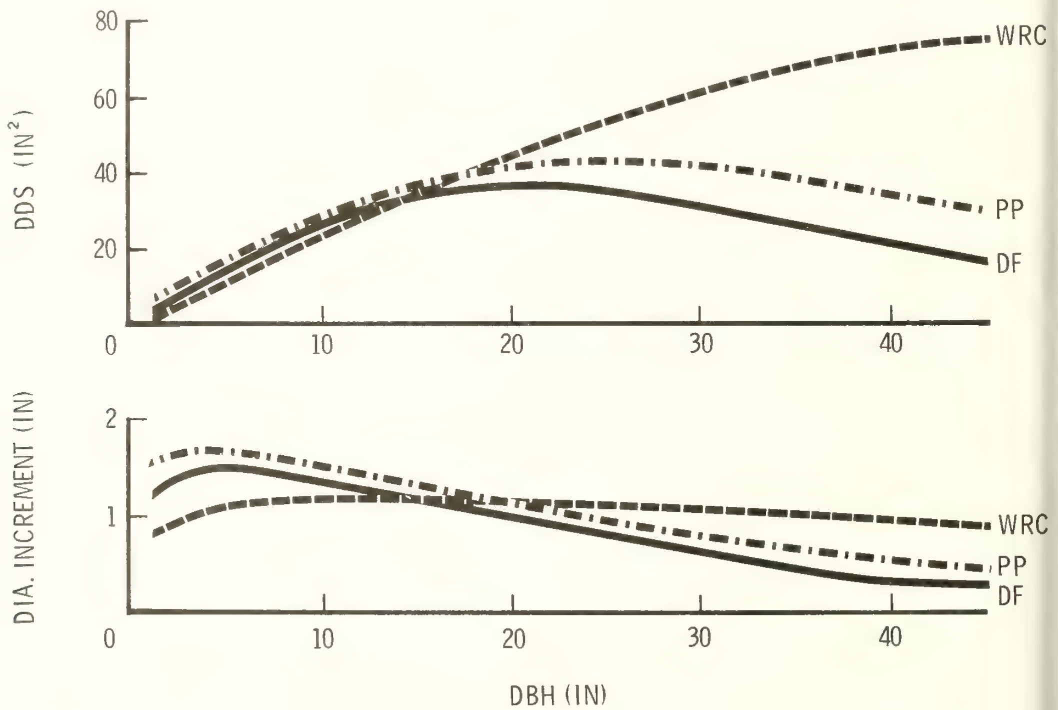
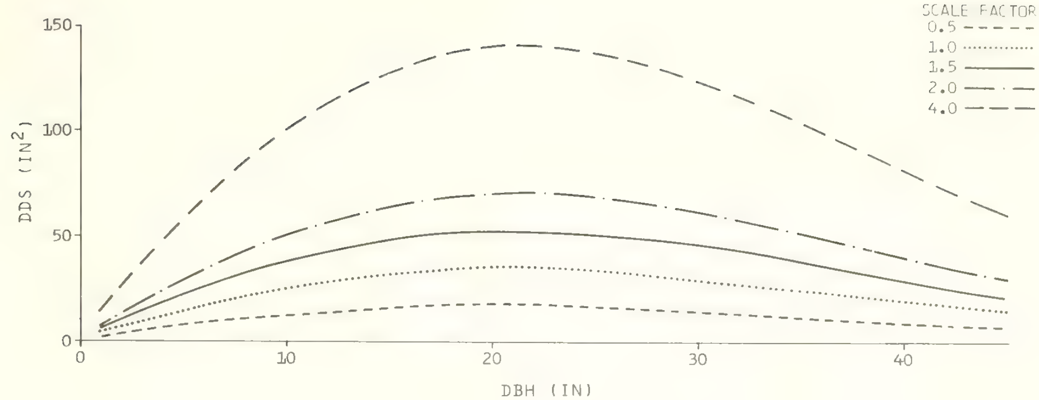


Figure 23.—Diameter increment and *dds* (see equations 7 and 8) predicted for three species assuming a *Thuja plicata/ Pachistima myrsinites* habitat type on the St. Joe National Forest. The slope is assumed to be level at 3,800 feet elevation. The trees depicted are dominants in medium density stands (basal area = 150 ft²/acre). The species are western redcedar (WRC), ponderosa pine (PP) and Douglas-fir (DF).



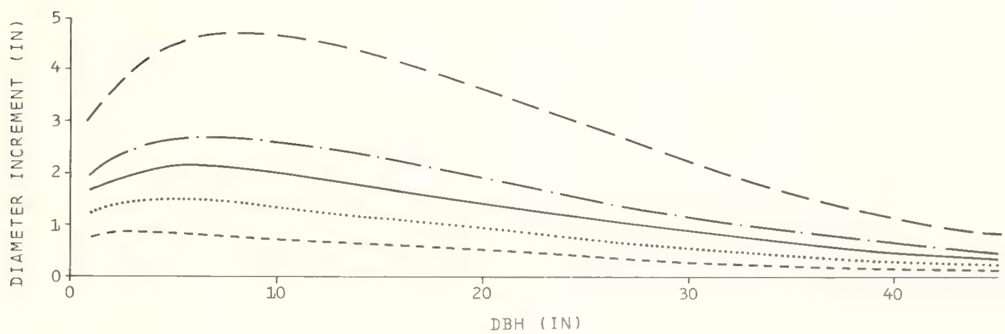


Figure 24.—The effect of scaling on the predictions of *dds* (see equations 7 and 8) and diameter increment. The species is Douglas-fir with other stand conditions as specified for figure 23. Note that the maximum of the diameter increment curve shifts to the right as the scale factor increases. The maximum of the *dds* curve remains at about 20 inches *DBH* regardless of scale factor.

he Influence of Site actors

Site factors are included in the model in two general ways. The effects of habitat type and location are readily observed but difficult to quantify. These effects are included in the model by varying intercepts. Slope, aspect, and elevation are treated as continuous variables.

The location intercepts were developed by first estimating coefficients for each National Forest. National Forests that had statistically similar coefficients were then grouped into location classes. This procedure was repeated to group habitat types into habitat classes, at which time the integrity of the location classes was reexamined.[9] As a result, when you move from one National Forest or habitat type to another, there is a discrete shift in the increment function (fig. 25).

We use a modification of Stage's (1976) transformation to incorporate aspect and slope as a continuous circular effect. The modification is the addition of a slope-squared term that allows optimum growth to occur at other than infinite or level slopes. The optimal aspect varies by species but, with the exception of the two hemlock species and lodgepole pine, is within 60° of due south (fig. 26 and 27). Most species prefer moderate slopes. Moderate slopes tend to be well drained with adequate soil, and the growing season is longer on the warmer southern exposures.

Elevation is also transformed so that an optimum is possible. That optimum normally occurs at an elevation that is in the middle of the range of species occurrence in northern Idaho (fig. 28). Although the optimal level of most predictor variables is within the range of species occurrence, the effects are independently estimated, and there is no guarantee that

[9]Habitat and location constants were estimated using the dummy variable technique. Statistical similarity implies that none of the estimated coefficients that are grouped into a class differs from any other at the 50 percent level of significance.

there exists a site at which all predictor variables are at their optimum level. For example, optimum growth of western redcedar is expected on a south aspect, 90 percent slope at an elevation of 2300 feet in a cedar/devil's club (code = 550) habitat type in the Nezperce or Clearwater National Forests. This combination of site factors would be difficult, if not impossible, to find.

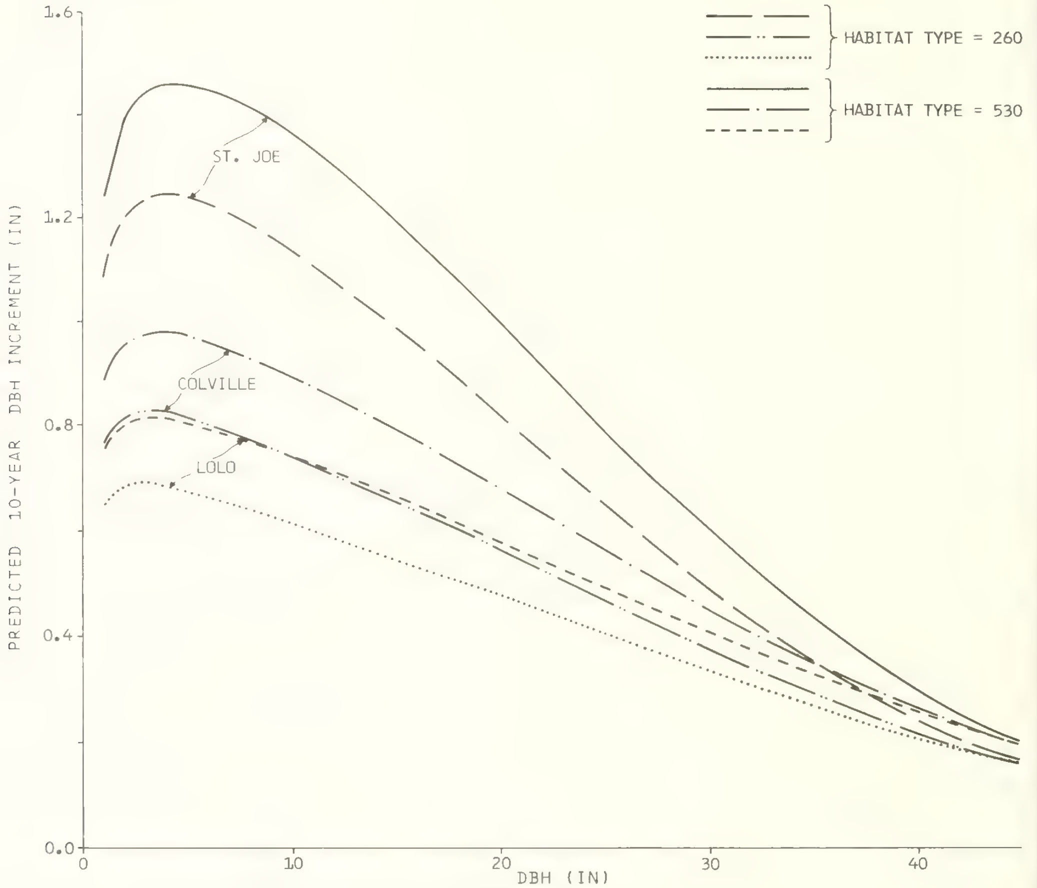


Figure 25.—The effect of habitat type and location on the prediction of diameter increment. The species shown is Douglas-fir; other conditions are as represented in figure 23.

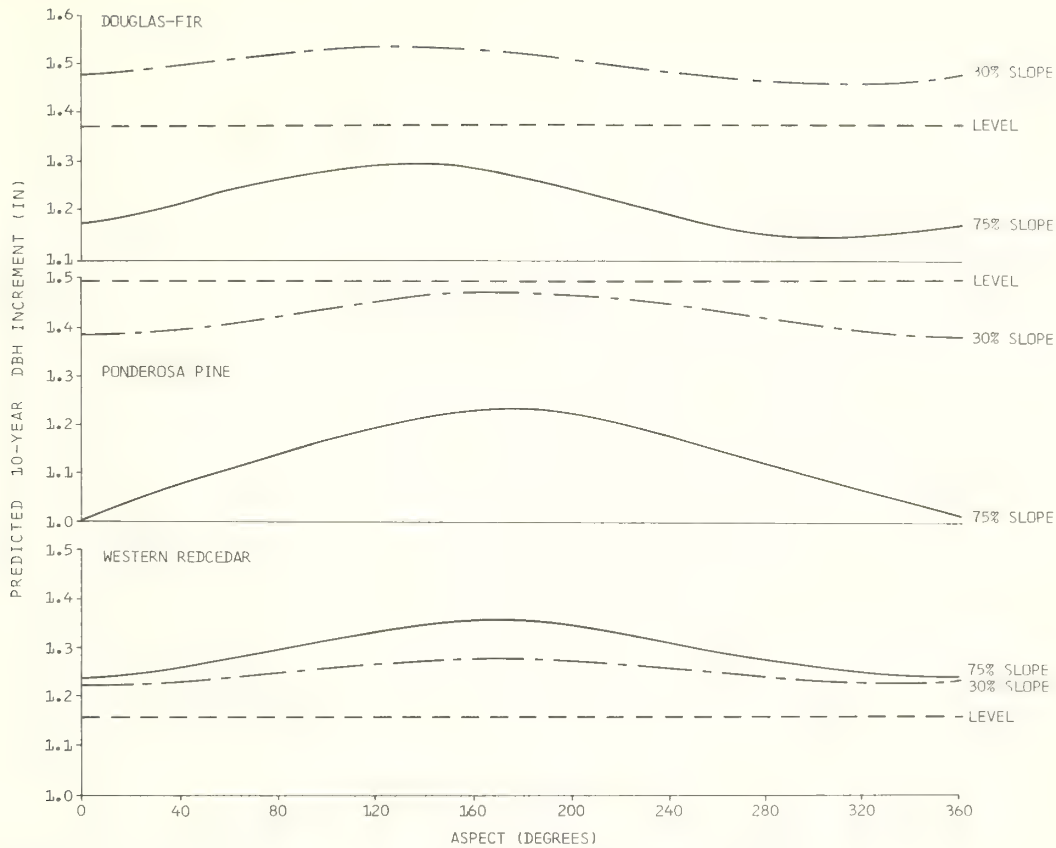


Figure 26.—The effect of aspect on diameter increment predictions for three different slopes. The species and site conditions are as specified in figure 23.

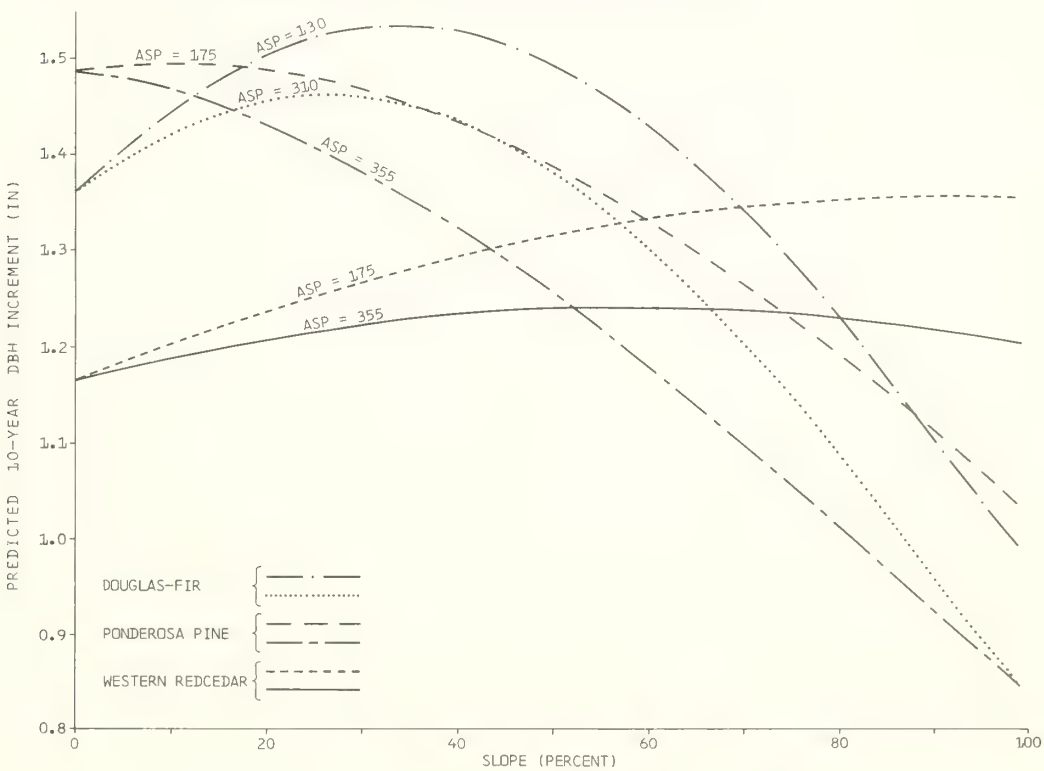


Figure 27.—The effect of slope on diameter increment predictions for two different aspects. Species and site conditions are as specified in figure 23.

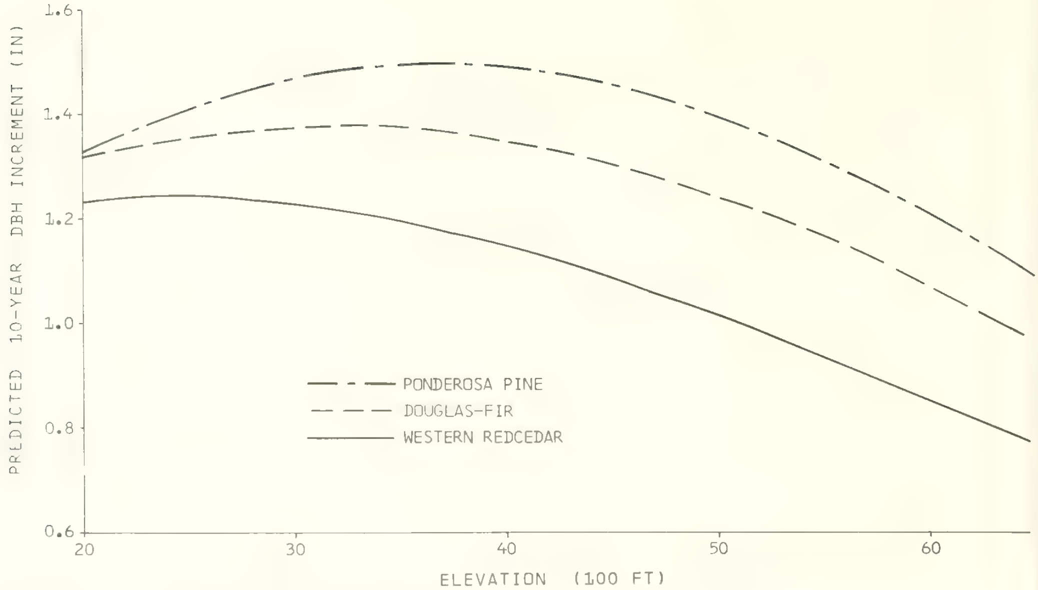


Figure 28.—The effect of elevation on diameter increment predictions. Three species (Douglas-fir, ponderosa pine, and western redcedar) are shown. Site conditions are as specified in figure 23.

Stand and Tree Characteristics that Can Be Managed

So far, we have described the features of the model over which we have no control. Through management, we can adjust stand density and the distribution of trees among size classes, and we can influence the development of crowns. Trees with large crowns and trees in dominant crown positions will grow more rapidly than subordinate trees with smaller crowns. As stand density increases, the growth rates of all trees will be suppressed (fig. 29). If we thin a stand by removing the smaller stems, the diameter increment of the residual stems will increase in proportion to the reduction in stand density. Over the long run, the residual trees will have larger crowns, which will enhance future development. If we remove the larger trees, the residual trees will respond with yet faster growth rates because we have improved their position in the canopy.

To this point, we have examined the growth model in two- or three-dimensional space. This viewpoint has made it easy to see the influence of a given variable on tree growth. However, this simplistic view can be misleading. The northern Idaho forest stand is a complex of species and size classes. Within this complex, any change in one of the variables used to predict growth will usually be associated with changes in one or more of the other predictor variables. We earlier displayed the relationship between *DBH* and diameter increment with all other variables held constant (fig. 23). If we reexamine this relationship in a stand whose development is simulated through time, each tree exhibits the classical unimodal increment curve (Assman 1970). However, some important differences result from the interactions of crown class, crown length, and stand density (fig. 30).

Within a stand, at any point in time, the largest diameter increment attained by any tree of a given species is likely to be attained by the largest tree of the species. The growth rate of a suppressed tree culminates at a smaller *DBH*, than does the growth rate of a dominant tree. In a relatively even-aged stand, however, culmination of all trees of a species will occur at about the same time. As a result, at any time, the relationship between diameter increment and *DBH* is monotonic or sigmoid increasing, with slope depending on stand density. Through time, this relationship flattens and its maximum decreases (fig. 31).

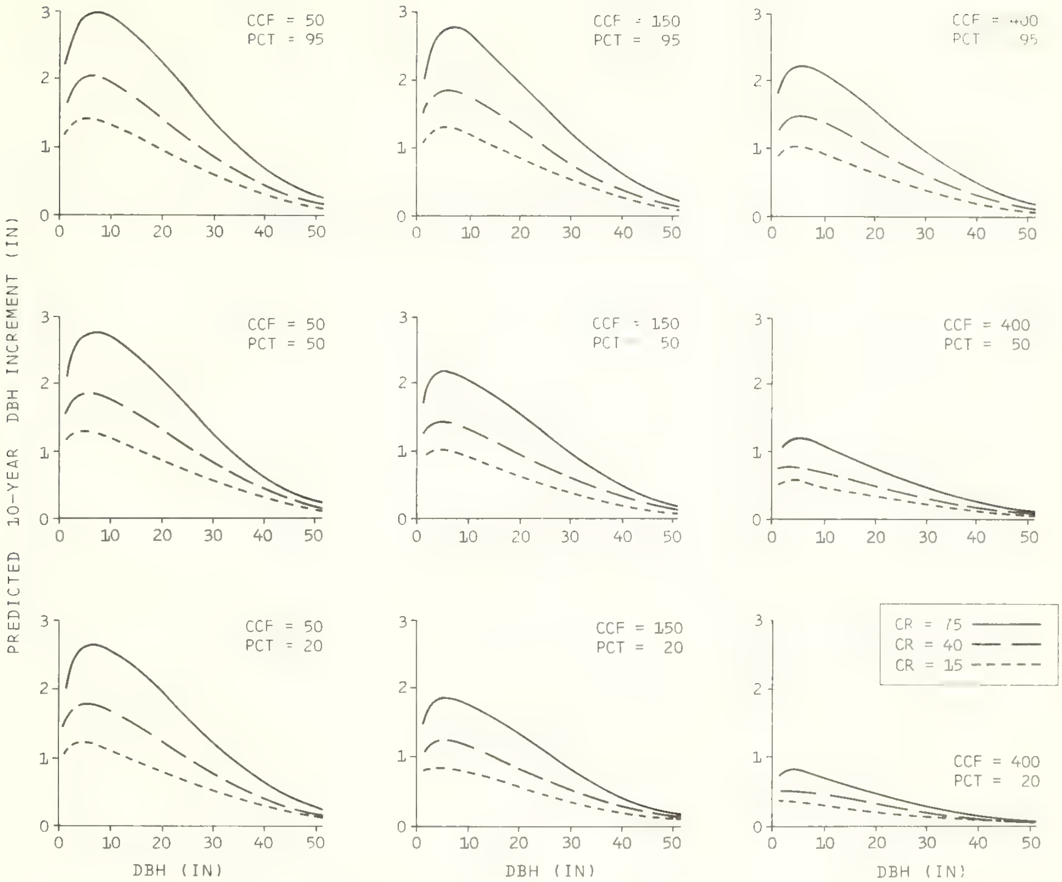


Figure 29.—The effects of dominance, crown ratio, and stand density on diameter increment predictions. Largest increments are attained by dominant trees with large crowns in open stands. As crowns shorten, as density increases, and as the tree is subordinated, the diameter increment predictions decrease.

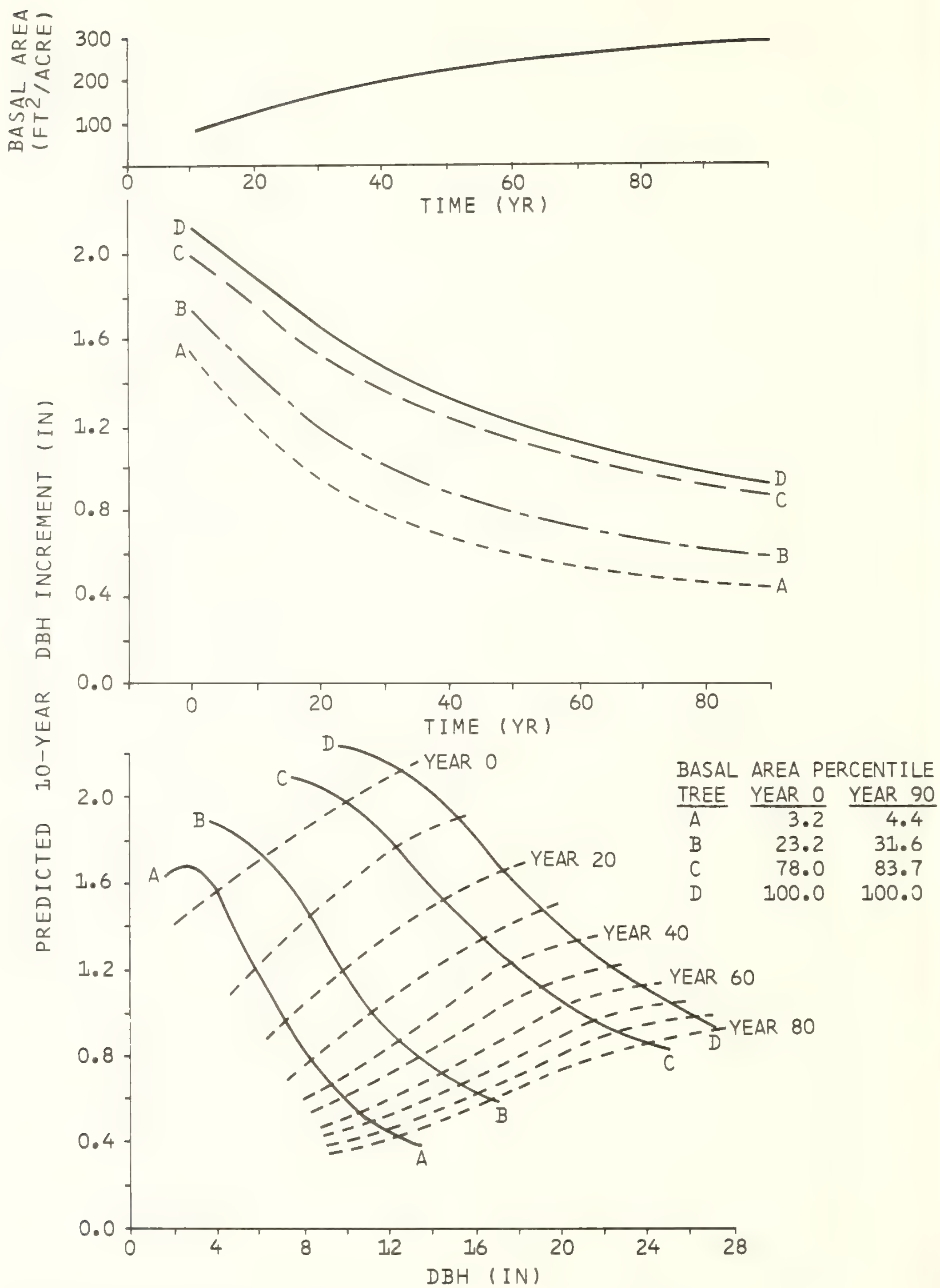


Figure 30.—Simulated development of four Douglas-fir trees through time. The larger trees always attain larger increments, although increments appear to converge over time. The *DBH* associated with the maximum in the diameter increment curve is shifted to the right for the larger trees.

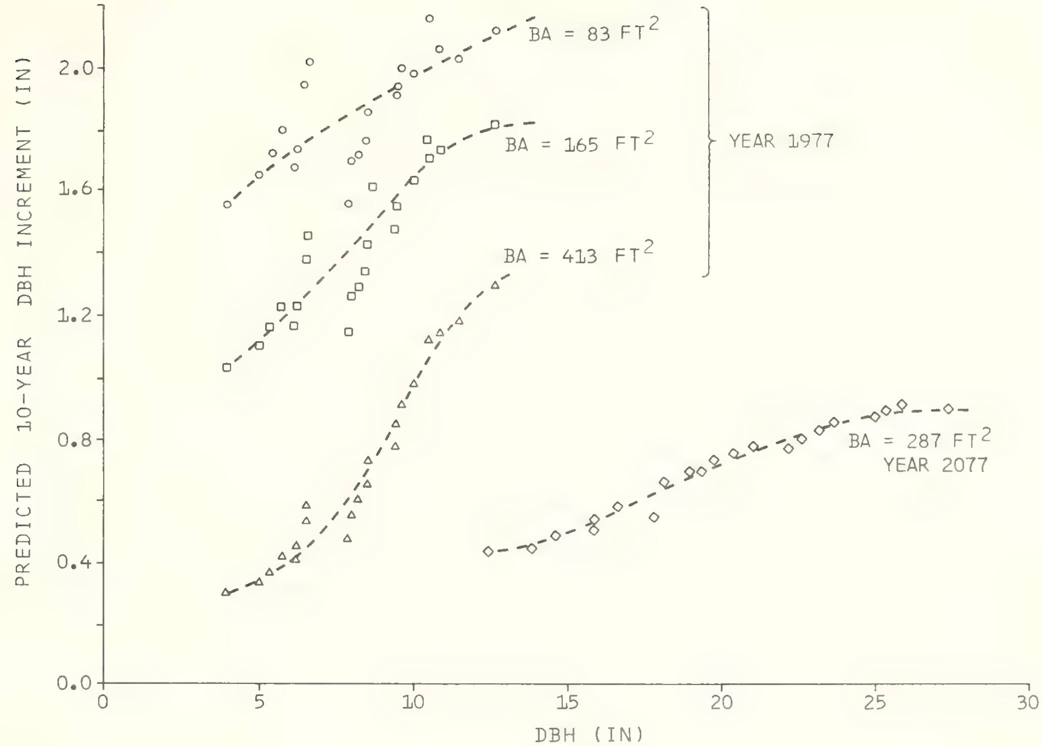


Figure 31.—Simulated increments versus *DBH* for all the trees in a stand. The three curves labeled 1977 show that density effects are felt most severely by the smaller trees in the stand. The curve labeled 2077 represents the predictions for the period 2067-2077 in the continuation of the projection for the stand that was least dense in 1977 (BA = 83 sq.ft.). These illustrations were prepared by using a single set of tree records and changing the number of plots assumed to be in the inventory. Initial crown ratios were computed by the program to reflect the influence of density.

THE HEIGHT INCREMENT MODEL

Formulation

Stage (1975) developed a periodic height increment model based on the differential of the allometric relationship between height (HT) and diameter (DBH). Periodic (10-year) height increment (HTG_1) is predicted as a function of HT, DBH, 10-year DBH increment (DG), species, and habitat type.

A series of modifications has been implemented in the basic model. Problems with overmature trees have been lessened to a great extent by addition of an HT^2 term to Stage's basic model. This term forces height increment to slow down in very tall trees even though diameter increment may still be quite substantial. In the modified form, coefficients of the DG and HT^2 terms are dependent on habitat type and coefficients of the DBH term are dependent on species:

$$\ln(HTG_1) = HAB + SPP + b_1 \cdot \ln(HT) + b_2 \cdot \ln(DBH) + b_3 \cdot \ln(DG) + b_4 \cdot HT^2 \tag{9}$$

where:

HAB = habitat dependent intercept

SPP = species dependent intercept

b_1 through b_4 = regression slope coefficients (table 14); b_2 is species dependent, b_3 and b_4 are habitat dependent.

Table 14.— Coefficients for the large tree height increment model (see equation 9)

Variable[1]										
ln (HT)	0.23315									
	Species[2]									
	WP	L	DF	GF	WH	C	LP	S	AF	PP
SPP	−0.5342	0.1433	0.1641	−0.6458	−0.6959	−0.9941	−0.6004	0.2089	−0.5478	0.7316
ln (DBH)	−.04935	−.3899	−.4574	−.0977	−.1555	−.1219	−.2454	−.5720	−.1997	−.5657
	Habitat Class[3]									
	1	2	3	4	5	6	7	8		
HAB	1.72222	1.74090	2.03035	1.19728	1.81759	2.14781	1.76998	2.21104		
ln(DG)	1.02372	.34003	.62144	.85493	.75756	.46238	.49643	.37042		
HT^2 ($\times 10^{-5}$)	−3.81	−4.46	−13.36	−3.72	−2.61	−5.20	−1.61	−3.63		

[1]Definition of variables:
- HT = Current height (feet)
- DBH = Current diameter at breast height (inches)
- DG = Predicted 10-year DBH increment (inches)
- SPP = Species dependent intercept
- HAB = Habitat dependent intercept

[2]No data were available for mountain hemlock; coefficients for cedar (C) are used for mountain hemlock predictions. Species codes are given in table 4.

[3]Definition of habitat classes:

Class	Codes included in class (see table 3)
1	250, 260, 280, 290, 310, 320, 330
2	690, 710, 720
3	130, 170, 660, 730, 830, 850, 999
4	420, 470
5	510, 620, 640, 670, 680
6	520
7	530
8	540, 550, 570, 610

In Stage's height increment model, many of the effects related to site characteristics and stand conditions are indirectly represented in the diameter increment term. For trees with less than 3 inches DBH, it is difficult to sample for periodic diameter increment. There may be less than 10 years' growth at breast height, and removal of an increment core could severely damage the tree. For very large trees, height increment measurement requires expensive stem analysis techniques; for small trees of most coniferous species, height increments for periods of up to 5 years can be obtained easily by counting whorls and measuring internodes.

Consequently, we developed an independent model to predict periodic (5-year) height increment (HTG_2) for small trees. This model has explicit site and stand density variables and no diameter increment term:

$$\ln(HTG_2) = LOC + HAB + SPP + b_1 \cdot \ln(HT) + b_2 \cdot CCF + b_3 \cdot SL \cdot \cos(ASP) + b_4 \cdot SL \cdot \sin(ASP) + b_5 \cdot SL \qquad (10)$$

where:

- LOC = Location dependent intercept (defined by National Forest boundaries)
- HAB = Habitat type dependent intercept
- SPP = Species dependent intercept
- CCF = Crown competition factor
- ASP = Stand aspect
- SL = Stand slope (percent/100)
- b_1 through b_5 = regression slope coefficients; b_1 and b_2 are dependent on species (table 15).

Table 15.—Coefficients for the small tree height increment model (see equation 10)

Variable[1]	
$\cos(ASP) \cdot SL$	0.22157
$\sin(ASP) \cdot SL$	–.12432
SL	–.10987

	Species[2]									
	WP	L	DF	GF	WH	C	LP	S	AF	PP
SPP	1.4700	1.6204	1.4932	0.9981	1.0202	0.8953	1.2336	1.0964	1.0667	1.7311
ln (*HT*)	.4214	.2716	.3907	.3487	.3417	.2354	.5843	.2827	.3740	.4485
CCF	–.00591	–.00654	–.00591	–.00391	–.00391	–.00391	–.00654	–.00391	–.00391	–.00654

	Habitat class[3]		
	1	2	3
HAB	–0.0941	0.0	–0.2146

	Location class[4]		
	1	2	3
LOC	0.0	–0.0480	–0.2785

[1]Definition of variables:
- *ASP* = Stand aspect
- *SL* = Stand slope ratio (percent/100)
- *SPP* = Species dependent intercept
- *HT* = Current tree height (feet)
- *CCF* = Stand crown competition factor
- *HAB* = Habitat dependent intercept
- *LOC* = Location dependent intercept

[2]Species codes given in table 4. No data were available for mountain hemlock; coefficients for cedar (C) are used for mountain hemlock predictions.

[3]Definition of habitat classes:

Class	Codes included (see table 3)
1	530
2	550, 570, 610
3	all others

[4]Definition of location classes:

Class	National Forests included
1	Clearwater, Nezperce
2	St. Joe, Coeur d'Alene
3	all others

With two independent models to predict the same attribute, we were unable to find a suitable tree size for transition between models. Regardless of the diameter chosen as a switching point, a discontinuity in the response surface existed. This problem was resolved by using a simple switching function. For trees with *DBH* less than 2 inches (1 inch for lodgepole pine), the height increment prediction is based entirely on the small tree model; for trees with *DBH* greater than 10 inches (5 inches for lodgepole pine), the prediction is based entirely on the large tree model. If *DBH* is between 2 and 10 inches (1 and 5 inches for lodgepole pine), the large tree prediction (HTG_1) is given weight of HWT, and the small tree prediction (HTG_2) is given a weight of (1-HWT) where

$$HWT = \begin{cases} (DBH - 1)/4 & \text{for lodgepole pine} \\ (DBH - 2)/8 & \text{for all other species} \end{cases}$$

hence,

$$HTG = HWT \cdot HTG_1 + (1 + HWT) \cdot HTG_2$$

Because the small tree height increments can be measured with relative ease, we have included a calibration procedure for the small tree height increment model that is analogous to the procedure used in the large tree *DBH* increment model. The median residual between observed and predicted height increments is computed on the logarithmic scale and incorporated in the prediction equation as an additional intercept term.

Examining the composite behavior of the model (fig. 32) reveals that the height increment curve increases rapidly to a maximum at 3 to 5 inches *DBH* and then gradually decreases, much in the fashion of the classical increment curve (Assman 1970). The effect of increasing density is to suppress height increment—directly through the *CCF* term in the small tree model, indirectly through the *DG* term in the large tree model (fig. 33).

In an undisturbed even-aged stand, the height and diameter increment models work together to produce increasingly flattened height-diameter curves over time (fig. 34).

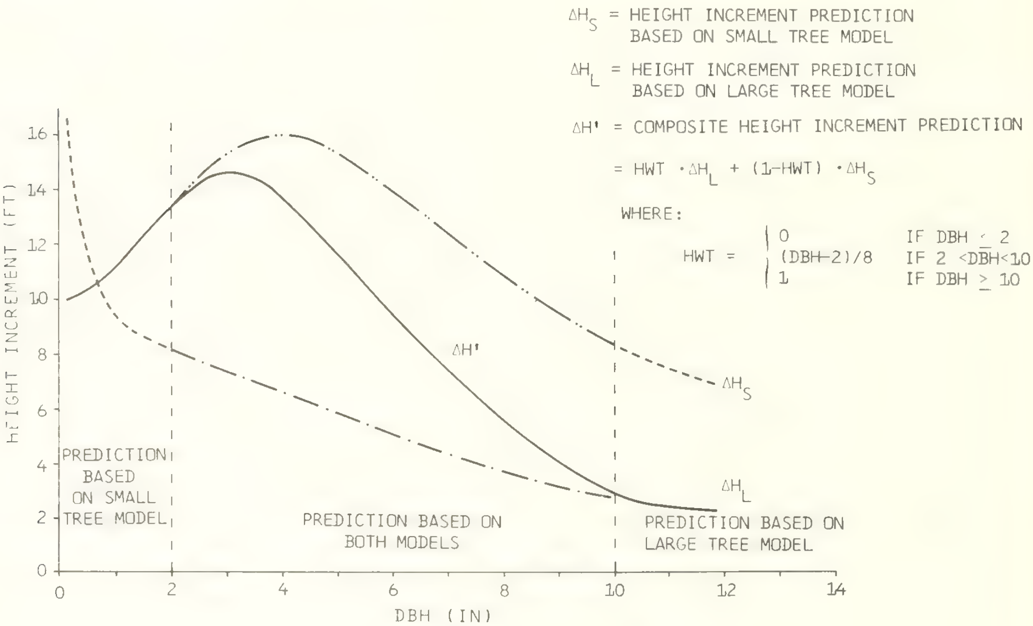


Figure 32.—Composite periodic height increment prediction based on two independent models; species is Douglas-fir.

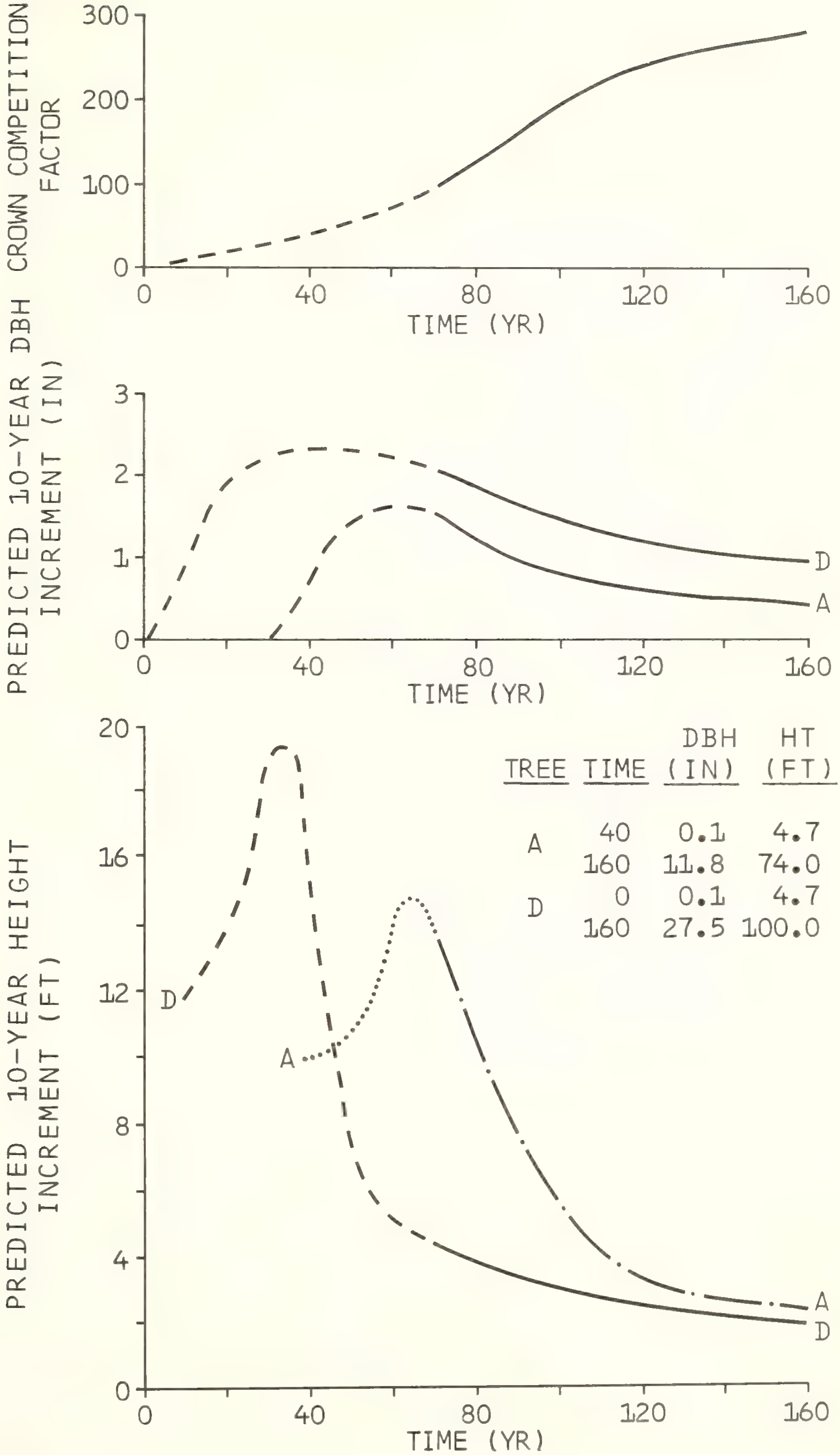


Figure 33.—Simulated increment predictions over time showing stand density and the corresponding height and diameter increments of a dominant (D) and an intermediate (A) Douglas-fir.

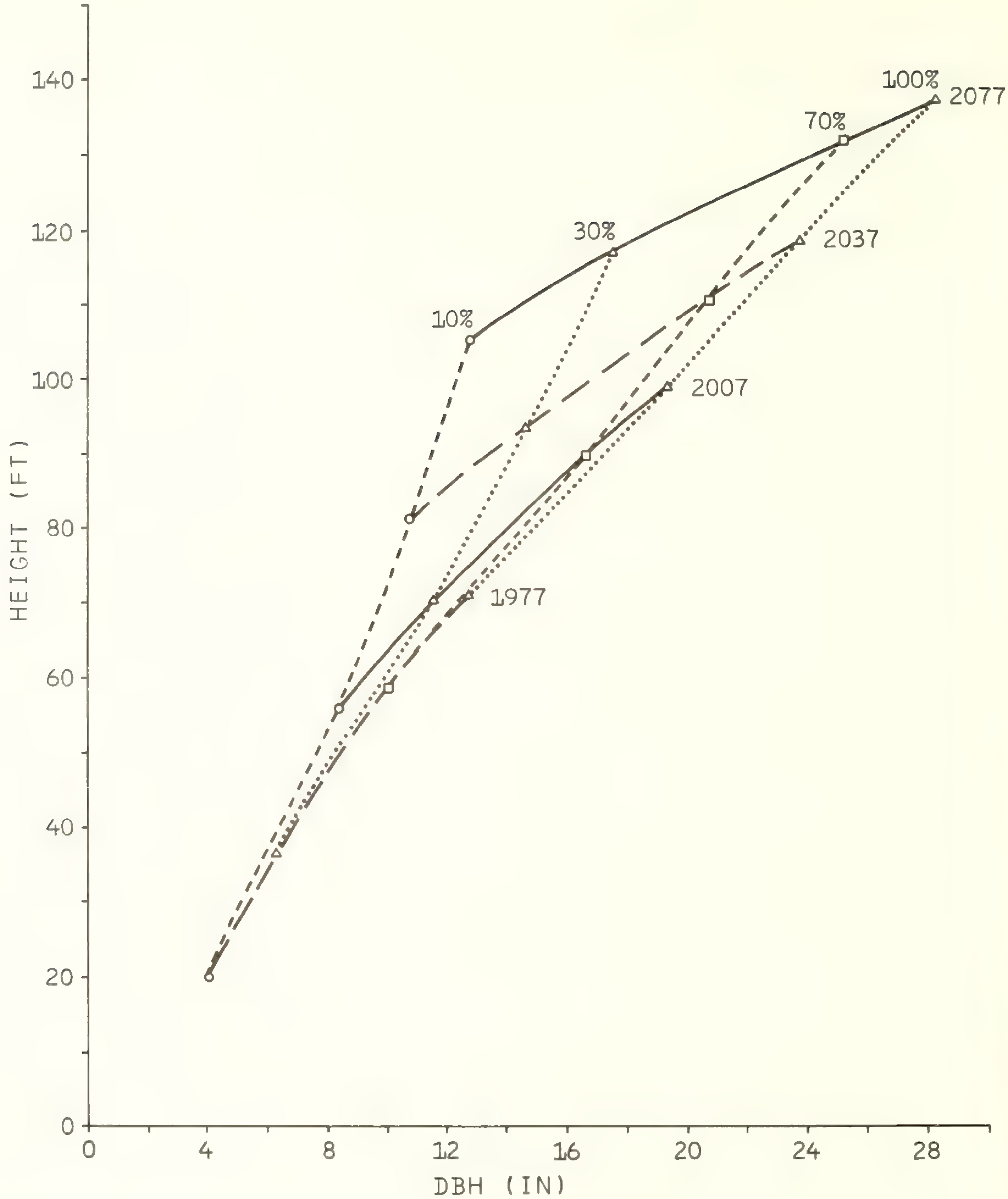


Figure 34.—Changes in the stand height-diameter curve over time; species is Douglas-fir. Percentages indicate approximate percentile points in the trees per acre distribution.

PREDICTING MORTALITY RATES

The Prognosis Model mortality predictions are intended to reflect background or normal mortality rates. The predictions are dependent on species, *DBH*, quadratic mean stand diameter, habitat type, trees per acre, and stand basal area. Three models are involved in the prediction. They are related with an intricate set of weighting functions so that overall rate prediction is continuous with respect to all of the predictor variables.

The Diameter-Based Individual Tree Model

Hamilton and Edwards (1976) developed a method for predicting individual tree mortality rate as a function of tree *DBH*. This method was subsequently used to develop a species-specific mortality model that is applicable to forests in the Inland Empire. Parameter estimates were derived from analysis of the USDA Forest Service Region 1 timber management inventory along with data from a mortality survey that utilized

large-scale aerial photography.[10] This diameter-based model (eq. 11) is the first step in our mortality rate calculation procedure.

$$R_d = \frac{1}{1 + e^{(b_0 + b_1 \cdot DBH + b_2 \cdot DBH^2)}} \tag{11}$$

where:

R_d = diameter-based individual tree annual mortality rate,

and b_1, b_2, and b_3 = species-specific coefficients (table 16).

Table 16.—Coefficients for the diameter-based mortality rate equation used in the Prognosis Model (see equation 11)

Species	b_0	b_1	b_2
Western white pine	5.45676	−0.01182	0.0
Western larch	5.26043	−.00971	.0
Douglas-fir	5.55086	−.01291	.0
Grand fir	5.16774	−.00777	.0
Western hemlock	4.28773	.0	.0
Western redcedar	6.06747	−.00865	.0
Lodgepole pine[1]	3.87794	.30780	−.01740
Engelmann spruce	6.41265	−.01273	.0
Subalpine fir	5.88697	−.03338	.0
Ponderosa pine	5.58766	−.00525	.0
Mountain hemlock	7.47709	−.03952	.0

[1]The coefficients for lodgepole pine are based on Lee's (1971) model for predicting average stand mortality rate as a function of mean stand *DBH*.

For many conditions, the diameter-based model yields acceptable results. The usual predictions of 0.3 to 0.7 percent mortality per year are within the range of expectations.

The diameter-based model, however, is insensitive to stand density. In situations where we would expect accelerated mortality due to suppression and competition, the diameter-based rates are too low. When stands are well- or overstocked, and mortality rates are predicted only with the diameter-based model, projected volume and basal area estimates substantially exceed normal yield table estimates. As a consequence, we developed two theoretical models to represent the effects of density on individual tree mortality rates. These models predict mortality rates that reflect approach to normality and approach to maximum basal area.

Approach to Normality

The first density-dependent model is based on the concept of approach to normality. It was developed using data from the yield tables for second-growth stands in the western white pine type (Haig 1932).

Normal stocking density in trees per acre (T_n) is computed from quadratic mean stand *DBH* (*QMD*):

$$T_n = 25000 \cdot [QMD - (-1)]^{-1.5881} \tag{12}$$

[10]Hamilton, D. A., Jr. 1981. Personal communication. Data and analysis on file at the Intermountain Forest and Range Experiment Station's Moscow Forestry Sciences Laboratory, Idaho.

Equation 12 is a hyperbola with a verticle asymptote at QMD equal to (-1). It is a restatement of the guide curve for the THINAUTO option (eq. 4 and fig. 5).

When current quadratic mean stand DBH and periodic change in quadratic mean stand DBH (G_p) are known, the normal stocking model can be used to estimate a normal periodic mortality rate (r_p):

$$r_p = \frac{T_{n0} - T_{n1}}{T_{n0}}$$

where:

T_{n0} = normal stocking estimate based on current quadratic mean stand DBH
$= 25000 \cdot (QMD + 1)^{-1.5881}$

and T_{n1} = normal stocking estimate based on predicted quadratic mean stand DBH at the end of the period
$= 25000 \cdot [(QMD + G_p) + 1]^{-1.5881}$

Applying this rate in a stand that was not normally stocked would not, however, cause stand density to approach normality.

To effect an approach to normality, we translate the guide curve (eq. 12) such that it passes through the point (QMD, S_0) where S_0 represents current stocking density in stems per acre. The equation is translated by adding a quantity Δ to the vertical asymptote,

$$S_0 = 25000 \cdot [QMD - (\Delta - 1)]^{-1.5881}$$

such that Δ is the difference between QMD and the diameter (D_n) that is associated with the value S_0 on the normal stocking curve (fig. 35).

$$D_n = e^{\left[\frac{\ln(25000) - \ln(S_0)}{1.5881}\right]} - 1$$

and $\Delta = QMD - D_n$

With this modified equation and an estimate of 10-year change in QMD (G_{10}), we predict the number of stems per acre 10 years hence (S_{10})

$$S_{10} = 25000 \cdot [(QMD + G_{10}1) - (\Delta -)]^{-1.5881}$$

Then,

$$R_n = 1 - \left[1 - \frac{(S_0 - S_{10})}{S_0}\right]^{0.1}$$

where R_n is the estimated annual mortality rate based on approach to normality. When R_n is less than R_d, it is set equal to R_d.

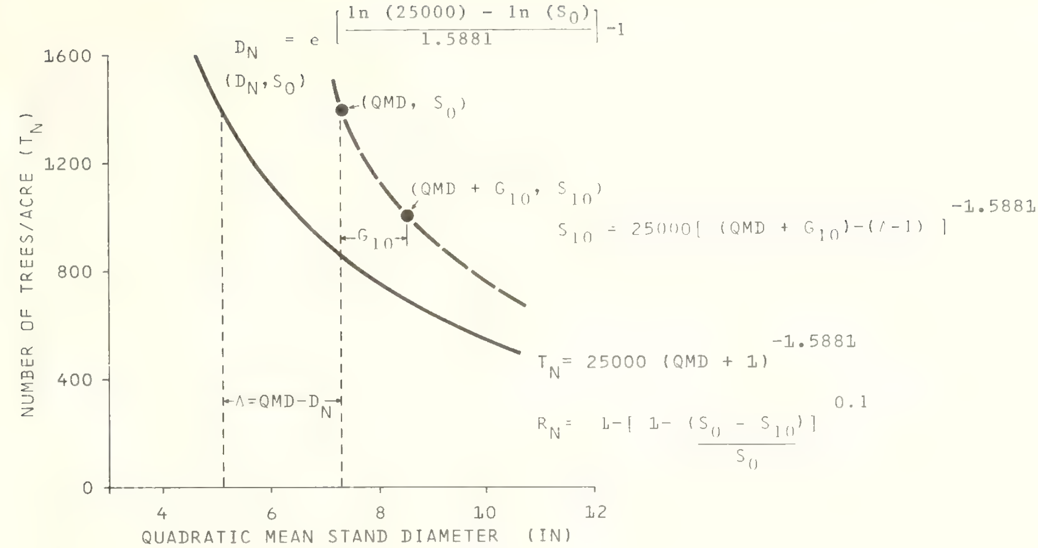


Figure 35.—Calculation of the annual "approach to normality" mortality rate (R_N). Inputs to the model are current stand quadratic mean *DBH* (*QMD*), current number of stems per acre (S_0), and an estimate of the 10-year change in *QMD* (G_{10}). The curve T_N represents normal stocking. By shifting the vertical asymptote an amount Δ, the curve is translated such that it passes through the point (QMD, S_0). The modified equation is solved for number of stems per acre 10 years hence (S_{10}). The values of S_0 and S_{10} are then used to compute R_N.

Approach to Maximum Basal Area

The second density-dependent mortality rate estimate is based on the assumption that there is a maximum basal area that a site can sustain and that this maximum varies by site quality. Data from the Region 1 timber management inventory and summaries from Pfister and others (1977) were used to define maximum attainable basal area (*BAMAX*) by habitat type (table 17). The rate estimate is designed to absorb an increasing proportion of gross stand basal area increment (*BAI*) as *BA* approaches *BAMAX*. If *BA* is exactly equal to *BAMAX*, the rate estimate will be such that *BAI* is equal to zero. As with the approach to normality procedure, estimation of the number of stems per acre 10 years hence (SB_{10}) is an intermediate step in the rate calculation.

$$SB_{10} = \frac{BA + \left(1 - \dfrac{BA}{BAMAX}\right) \cdot BAI}{TB_{10}}$$

where

TB_{10} = average basal area per tree 10 years hence
$= 0.005454154 \cdot (QMD + G_{10})^2.$

Then,

$$R_b = 1 - \left\{1 - \left[\frac{(S_0 - SB_{10})}{S_0}\right]\right\}^{0.1}$$

where

R_b = the annual approach to maximum basal area mortality rate.

Table 17.—Values used for *BAMAX* in the Inland Empire version of the Prognosis Model

Habitat code	*BAMAX*	Habitat code	*BAMAX*
	Ft²/acre		*Ft²/acre*
130	140	550	500
170	220	570	390
250	250	610	390
260	310	620	440
280	240	640	180
290	270	660	290
310	310	670	400
320	310	680	350
330	200	690	390
420	310	710	260
470	290	730	220
510	330	830	220
520	380	850	160
530	440	999	300

At this point, we make an adjustment to reflect the increased probability of death that is normally associated with advanced age. In an even-aged stand, the larger trees are normally the more vigorous trees and would be expected to have a greater chance of survival than trees in a competitively less advantageous position. Stands in the Inland Empire, however, are predominantly composed of multiple age classes, and in sawtimber stands, the largest trees are approaching overmaturity. Our adjustment has no effect when *QMD* is less than 10 inches or when the *DBH* of the subject tree is less than *QMD*. When *DBH*'s are in the range normally associated with managed stands, the effect of the adjustment is limited. For example, when *QMD* is equal to 15 inches, the mortality rate for a tree with *DBH* equal to 30 inches is approximately 1.06 times the rate for a tree with *DBH* less than or equal to *QMD*. When *QMD* is equal to 30 inches, however, a situation that would normally indicate an old stand, the mortality rate for a tree with *DBH* equal to 60 inches would be twice the rate for a tree with *DBH* less than or equal to *QMD*. The adjustment is a multiplier (*COSMIC*) that is applied to the rate R_b:

$$R_{bc} = COSMIC \cdot R_b$$

where

$$COSMIC = \frac{1 + \dfrac{Z \cdot DBH}{QMD}}{1 + Z}$$

$$Z = \begin{cases} 0 & \text{when } (QMD \leq 10) \text{ or } (DBH \leq QMD) \\[2ex] \dfrac{(QMD - 10)^2}{400} & \text{when } (QMD > 10) \text{ and } (DBH > QMD) \end{cases}$$

and R_{bc} = the adjusted approach to maximum basal area mortality rate.

Combining the Mortality Rate Estimates

The weight given to each rate estimate in the development of a combined annual mortality rate estimate for a tree (R_t) depends on stand basal area and tree *DBH*. When stand basal area is greater than *BAMAX*, the rates R_d and R_n are ignored and R_{bc} is inflated by the ratio of *BA* to *BAMAX*:

$$R_t = R_{bc} \cdot \left(\frac{BA}{BAMAX} \right)$$

for ($BA \geq BAMAX$).

When stand basal area is less than *BAMAX* but tree *DBH* is greater than or equal to 10 inches, the approach to normality rate (R_n) is ignored and the combined rate is computed as follows:

$$R_t = R_{bc} \cdot \frac{BA}{BAMAX} + R_d \cdot \left(1 - \frac{BA}{BAMAX} \right)$$

for ($BA < BAMAX$) and ($DBH \geq 10$).

When the tree *DBH* is less than *BAMAX*, all three rate estimates are used to predict R_t:

$$R_t = R_{bc} \cdot \frac{BA}{BAMAX} + \left(1 - \frac{BA}{BAMAX} \right) \left[R_d \cdot \frac{DBH}{10} + R_n \cdot \left(1 - \frac{DBH}{10} \right) \right]$$

for ($BA < BAMAX$) and ($DBH < 10$).

Finally, the annual rate prediction is converted to a survival rate and compounded to estimate periodic rate (R_p) for a *p*-year period

$$R_p = 1 - (1 - R_t)^p$$

Model Behavior

When there are a relatively large number of small trees in the stand, the predicted mortality rates for small trees are relatively high. The mortality rates predicted for large trees are unaffected by the number of trees in the stand. As stand basal area increases, however, mortality rates for all trees increase (fig. 36).

On the stand level, the effect of increasing density on mortality rates can be observed by comparing accretion and net total cubic foot volume increment (fig. 37). With all other factors held constant (including time), accretion continues to increase, even at very high levels of stand basal area. As stand basal area approaches *BAMAX*, however, net volume increment rapidly approaches zero.

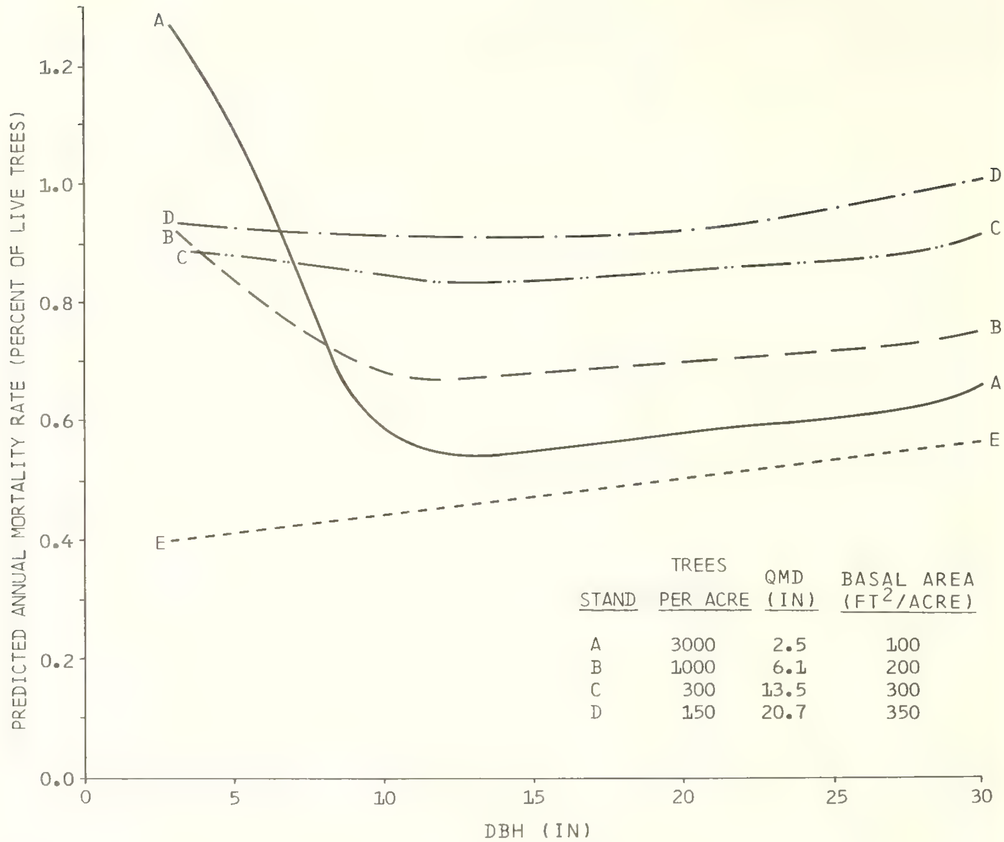


Figure 36.—Individual tree mortality rates for trees of different *DBH*. Curves A,B,C, and D reflect different assumptions about stand density. Curve E is the rate predicted on the basis of *DBH* alone (equation 11).

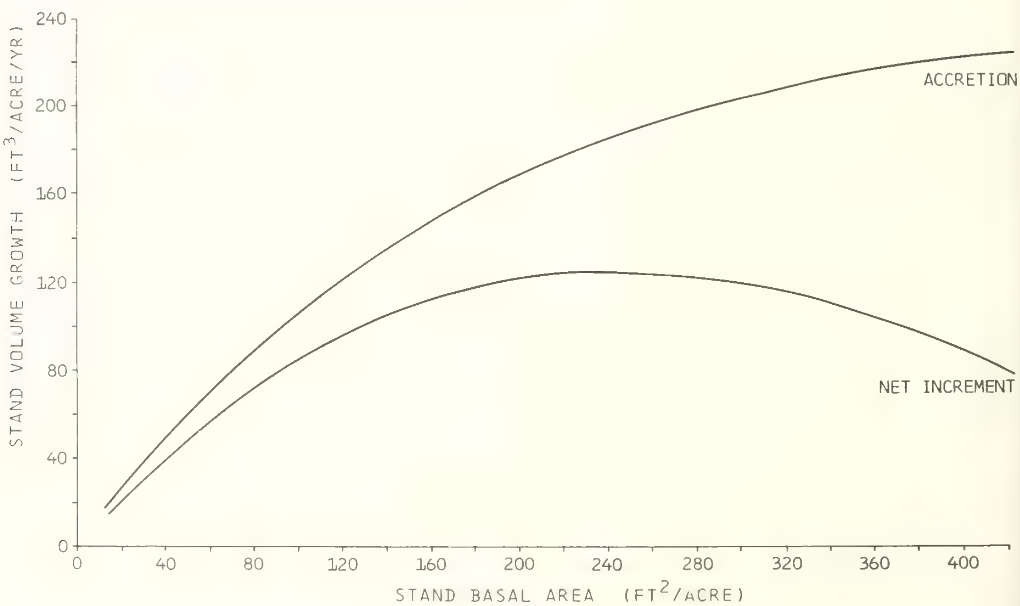


Figure 37.—The effect of stand density on stand growth rates, all other factors held constant.

CHANGE IN CROWN RATIO

Formulation

The ratio of live crown length to total tree height is a good indicator of tree vigor. As such, it is an important predictor of periodic increment even though it has substantial shortcomings.

Crown ratio changes slowly with time, but it does change. However, very limited data describing the rate of change are available. The dearth of data can be attributed in part to the difficulty of objective crown ratio measurement. Limbs are not systematically distributed on the bole, and it is difficult to pinpoint a base of live crown that is physiologically meaningful. As a result, crown ratio measurements and predictions are subjective, imprecise, and prone to error. Nevertheless, we feel that the utility of crown ratio as a predictor substantially outweighs the difficulties associated with its measurement.

The model used to predict change in crown ratio was developed by Hatch (1980). The model predicts crown ratio as a function of species, habitat type, stand basal area (BA), crown competition factor (CCF), tree DBH, tree height (HT), and the tree's percentile in the stand basal area distribution (PCT):

$$\begin{aligned}\ln(CR) = {} & HAB + b_1 \cdot BA + b_2 \cdot BA^2 + b_3 \cdot \ln(BA) + b_4 \cdot CCF + b_5 \cdot CCF^2 \\ & + b_6 \cdot \ln(CFF) + b_7 \cdot DBH + b_8 \cdot DBH^2 + b_9 \cdot \ln(DBH) \\ & + b_{10} \cdot HT + b_{11} \cdot HT^2 + b_{12} \cdot \ln(HT) + b_{13} \cdot PCT \\ & + b_{14} \cdot \ln(PCT) \qquad (13)\end{aligned}$$

where:

HAB = intercept term that depends on species and habitat type (tables 18 and 19)

b_1 through b_{14} = species dependent regression coefficients (table 18).

Table 18.— Coefficients for the crown ratio equation (see eq. 13)

Variable[1]	Class	Species[2] WP	L	DF	GF	WH	C	LP	S	AF	PP	MH
Habitat class intercepts[3]	1	0.8884	0.06533	0.8643	−0.2304	−0.2413	−1.6053	−0.3785	0.05351	0.09453	−0.9436	0.4649
	2	.7309	.03441	.7271	−.5421		−1.7128	−.4142	−.05031	−.07740	−.8654	.3211
	3	.9347	.2307	.9840	−.4343			−.3984	.1075	.07113	−.8849	.1970
	4	.9888	.1661	.8127	−.3759			−.2987	−.1872	.2039	−.9067	.2295
	5	.9945	−.1253	.8874	−.4129			−.3810	.01729	.06176	−.8783	.3383
	6	1.1126	−.05018	.7055	−.4879			−.4087	.03667	.1513	−1.0103	.3450
	7	1.0263	.1100	.7708	−.2674			−.3577	.01885	.09086	−1.0268	
	8		.08113	.7849	−.1941			−.2994	.09102	.1580	−1.0050	
	9		.1782	.8038				−.2486	.1371	.09229	−1.0301	
	10		.03919	.8742				−.2863	.08368	.01551		
	11		.2107	.8232				−.1968	.1230			
	12			.8415				−.4931	−.02365			
	13			.9759				−.2675				
	14							−.5625				
BA		.0	−.00204	.0	−0.00183	.0	.0	.0	−.00203	−.00190	−.00216	−.00264
*BA*² (× 10⁻⁶)		.0	.0	.0	.0	−1.902	.0	.0	.0	.0	.0	.0
ln(*BA*)		−.34566	.0	.0	.0	.0	.17479	.0	.0	.0	.0	.0
CCF		.0	.0	.0	.0	.0	−.00183	.0	.0	.0	.0	.0
*CCF*²(× 10⁻⁶)		.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	5.12
ln (*CCF*)		.0	.0	−.15334	.0	.0	.0	−.18555	.0	.0	.0	.0
DBH		.03882	.0	.0	.0	.03027	−.00560	.0	.0	.0	.0	.0
*DBH*²		−.00070	.0	.0	.0	−.00055	.0	.0	.0	.0	.0	.0
ln ((*DBH*)		.0	.30066	.33840	.24293	.0	.0	.53172	.29699	.23372	.26558	.0
HT		.0	.0	.0	.0	.0	.0	−.02989	.0	.0	.0	.0
*HT*²		.0	.0	.0	.0	.0	.0	.00011	.0	.0	.0	.0
ln(*HT*)		−.21217	−.59302	−.59685	−.25601	−.25776	.0	.0	−.38334	−.28433	−.31555	−.25138
PCT		.00301	.0	.0	.0	.0	.0	.00420	.0	.00190	.0	.0
ln(*PCT*)		.0	.19558	.16488	.07260	.06887	.11050	.0	.09918	.0	.16072	.05140

[1] Definition of variables:
BA = Stand basal area (square feet per acre)
CCF = Stand crown competition factor
DBH = Current diameter at breast height (inches)
HT = Current height (feet)
PCT = Current percentile in the stand basal area distribution

[2] Species codes are given in table 4.

[3] Habitat types are mapped onto habitat classes as shown in table 19.

Table 19.— Map of habitat types onto habitat classes by species for the crown ratio model (see eq. 13)

Habitat	Species[1]										
	WP	L	DF	GF	WH	C	LP	S	AF	PP	MH
130	2	2	2	2	1	1	2	2	2	2	1
170	2	2	2	2	1	1	2	2	2	2	1
250	2	2	2	2	1	1	2	2	2	4	1
260	2	2	4	2	1	1	2	2	2	1	1
280	2	2	4	2	1	1	2	2	2	1	1
290	2	2	4	2	1	1	2	2	2	1	1
310	2	2	6	2	1	1	4	2	2	5	1
320	2	3	7	2	1	1	5	3	2	6	1
330	2	2	4	2	1	1	5	2	2	1	1
420	2	4	8	1	1	1	2	1	2	1	1
470	2	4	8	1	1	1	2	1	2	1	1
510	2	5	5	2	1	1	6	2	2	8	1
520	3	6	9	3	1	1	7	4	2	7	2
530	4	7	10	4	1	1	8	5	3	9	2
540	4	7	10	4	1	1	8	5	4	9	2
550	4	7	10	4	1	1	8	5	4	9	2
570	5	8	11	5	1	2	9	6	4	3	3
610	5	8	11	5	1	2	9	6	4	3	3
620	5	4	8	6	1	2	10	7	5	3	4
640	6	1	1	1	1	1	11	8	6	1	1
660	6	10	12	7	1	1	11	8	6	1	1
670	1	9	12	7	1	1	12	9	7	1	1
680	6	10	13	7	1	1	11	8	6	1	5
690	1	1	1	1	1	1	1	10	1	1	1
710	7	11	3	8	1	1	13	11	8	1	6
720	1	1	1	1	1	1	1	1	1	1	1
730	6	1	3	7	1	1	14	1	9	1	1
830	6	1	1	1	1	1	3	12	10	1	1
850	6	1	1	1	1	1	3	12	10	1	1
999	6	2	1	1	1	1	11	8	6	1	1

[1]Species codes are given in table 4.

To estimate change in crown ratio, we predict crown ratio based on stand and tree attributes at the beginning and at the end of a cycle. We then subtract the first prediction from the second to obtain a difference. This difference is added to the actual crown ratio to effect the change.

There are some additional operational constraints on this crown model. Theoretically, crowns should just touch when *CCF* is equal to 100. Below this threshold, we assume that the effect of density will be negligible. When *CCF* is less than 100, predictions made at the end of the cycle use the same *CCF* and *BA* values that were used to make predictions at the start of the cycle. We also assume that thinning will encourage crown development. However, when the stand is thinned from below, *PCT* is reduced for the residual trees, with the result that predicted crowns are smaller. To avoid this anomaly, when the stand is thinned we use the same *PCT* values when making predictions at both the start and the end of the cycle.

Behavior

For most species, crown ratio decreases as the tree gets larger. A dominant tree (as measured by *PCT*) tends to have a larger crown than a similar-sized tree in a subordinate crown position (assuming the two trees are in different stands). The effect of increasing stand density is to reduce crown ratio. However, as trees become large, the predicted changes in crown ratio become very small (fig. 38).

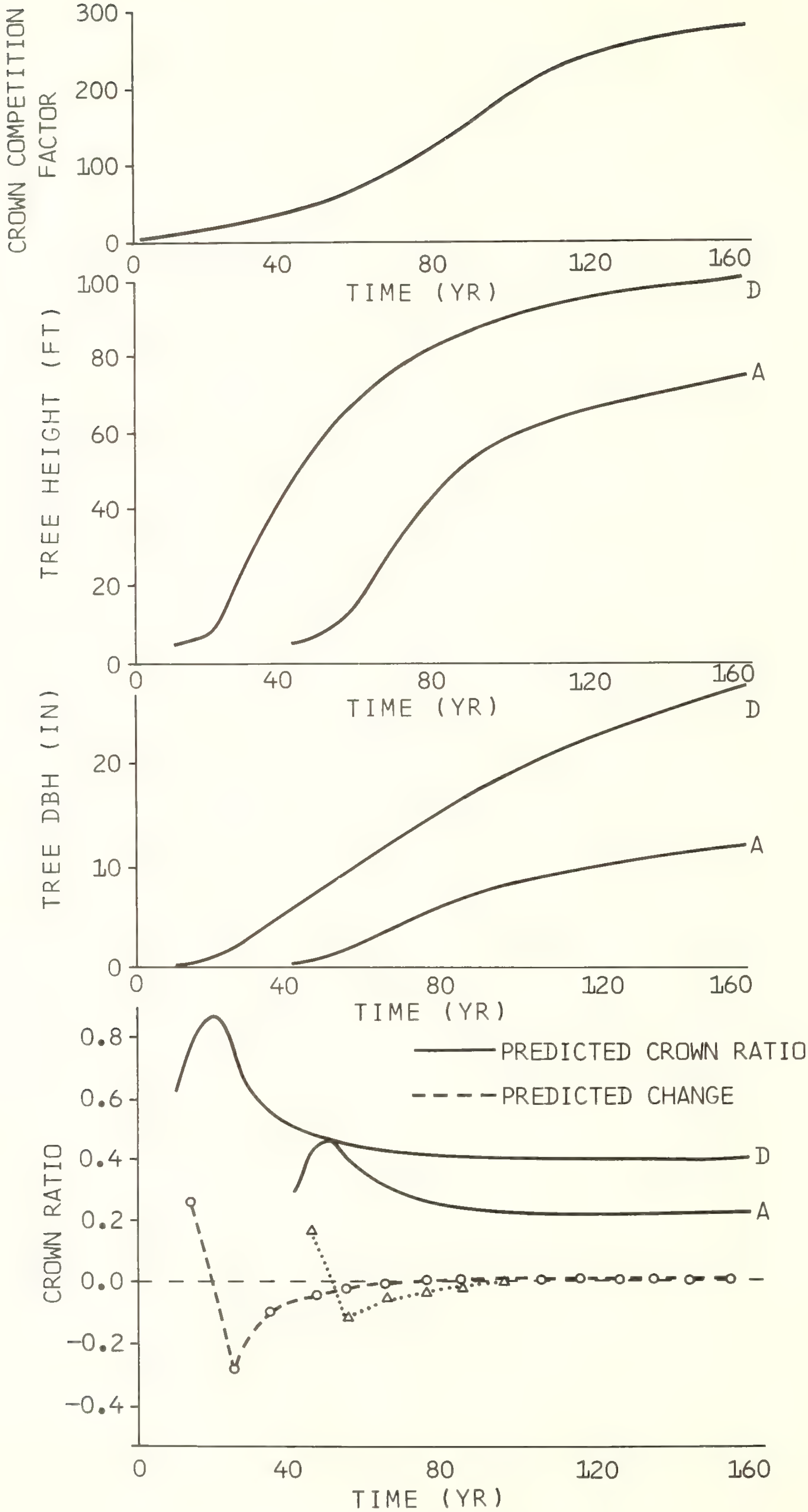


Figure 38.—Increase in stand density, height, and *DBH* over time. The trees shown are in dominant (D) and intermediate (A) crown positions. The lower graph shows how crown ratio changes relative to the other variables.

VOLUME CALCULATIONS

Individual tree volumes are computed to three merchantability standards. Calculations for total cubic foot volume (V_t) and Scribner board foot volume (V_b) are based on formulae involving transformations of total height (HT) and diameter breast height (DBH). An additional cubic foot volume estimate is derived from the total cubic foot estimate by using a Behre hyperbola to approximate tree form (Monserud 1980).

Total Cubic Volume

All of the total cubic foot volume equations, except for the equation for lodgepole pine, are of the general form:

$$V_t = b_0 + b_1 (DBH)^2 \cdot HT + b_2 \cdot DBH \cdot HT \tag{14}$$

The lodgepole pine equation is of the form:

$$V_t = b_0 (DBH)^{b_1} \cdot (\mathrm{HT})^{b_2} \tag{15}$$

where:

b_0, b_1, and b_2 = species-dependent regression coefficients (table 20).

The lodgepole pine equation was developed by Brickell,[11] and the ponderosa pine equations were developed by Myers (1964). The equations for all other species are from Stage (1966).

Table 20.—Coefficients for the total cubic foot volume equations; volume is computed from diameter breast height and total height (see eq. 14 and 15)

Species	Equation number	Coefficients		
		b_0	b_1	b_2
Western white pine	14	0.0	0.00233	0.0
Western larch	14	.0	.00184	.0
Douglas-fir	14	.0	.00171	.00386
Grand fit	14	.0	.00234	.0
Western hemlock	14	.0	.00219	.0
Western redcedar	14	.0	.00205	.0
Lodgepole pine	15	.00278	1.09410	1.04880
Engelmann spruce[1]	14	.0	.00171	.00386
Subalpine fir[1]	14	.0	.00171	.00386
Ponderosa pine:				
$(DBH)^2 \cdot HT \leq 6000$	14	.03029	.00221	.0
$(DBH)^2 \cdot HT > 6000$	14	– 1.55710	.00247	.0
Mountain hemlock[2]	14	.0	.00219	.0

[1]The equation for Douglas-fir is used to predict volumes for subalpine fir and Engelmann spruce.
[2]The equation for western hemlock is used to predict volumes for mountain hemlock.

[11]Brickell, J. E. 1966. Personal communication, unpublished analysis on file with Leader, Quantitative Analysis of Forest Management Practices and Resources for Planning and Control Research Work Unit (INT-1302), USDA Forest Service, Intermountain Forest and Range Experiment Station, Moscow, Idaho.

Board Foot Volume

The board foot volume equations compute Scribner board foot volume to an 8-inch top assuming a 9-inch minimum *DBH* and a 1-foot stump. The equations were developed by Kemp[12] and are of the form:

$$V_b = b_0 + b_1 \cdot (DBH)^2 \cdot HT \tag{16}$$

where:

b_0 and b_1 = regression coefficients that are dependent on species and *DBH* (table 21).

Other Merchantability Standards

The Prognosis Model computes cubic foot volume to an additional merchantability standard. The minimum *DBH*, top diameter, and stump height for this standard can be controlled by using the VOLUME keyword (see discussion in the section titled STAND MANAGEMENT OPTIONS). The default merchantability limits are:

Stump height	= 1 ft
Top diameter	= 4.5 inches
Minimum *DBH*	= 6.0 inches for lodgepole pine
	= 7.0 inches for all other species.

Table 21.—Coefficients for the board foot volume equation (Scribner board foot to an 8-inch top); volume is predicted from diameter breast height and total height (see eq. 16)

	Coefficients			
	$9.0 < DBH \leq 20.5$ in		$DBH > 20.5$ in	
Species	b_0	b_1	b_0	b_1
Western white pine	26.729	0.01189	32.516	0.01181
Western larch	29.790	.00997	85.150	.00841
Douglas-fir	25.332	.01003	9.522	.01011
Grand fir	34.127	.01293	10.603	.01218
Western hemlock	37.314	.01203	50.680	.01306
Western redcedar	10.742	.00878	4.064	.00799
Lodgepole pine	8.059	.01208	14.111	.01103
Engelmann spruce	11.851	.01149	1.620	.01158
Subalpine fir	11.403	.01011	124.425	.00694
Ponderosa pine	50.340	.01201	298.784	.01595
Mountain hemlock	37.314	.01203	50.680	.01306

Merchantable volumes are calculated by using the Behre hyperbola (Behre 1927) to approximate stem form. This function has a closed form integral that can be solved readily for variable limits of integration (Monserud 1980).

[12]Kemp, P. D. 1956. Region 1 volume tables for cruise computations, USDA Forest Service, Northern Region Handbook R1-2430-31, Missoula, Mont.

Predicted Values

Regardless of the merchantability standards, volume is approximately proportional to *DBH* cubed. However, because periodic *DBH* and height increments decrease over time, the relationship between volume and time is more or less linear (fig. 39). As expected, the absolute difference between merchantable and total cubic foot volume increases with time. The relative difference decreases with time, however, and for large trees, differences are trivial (fig. 40).

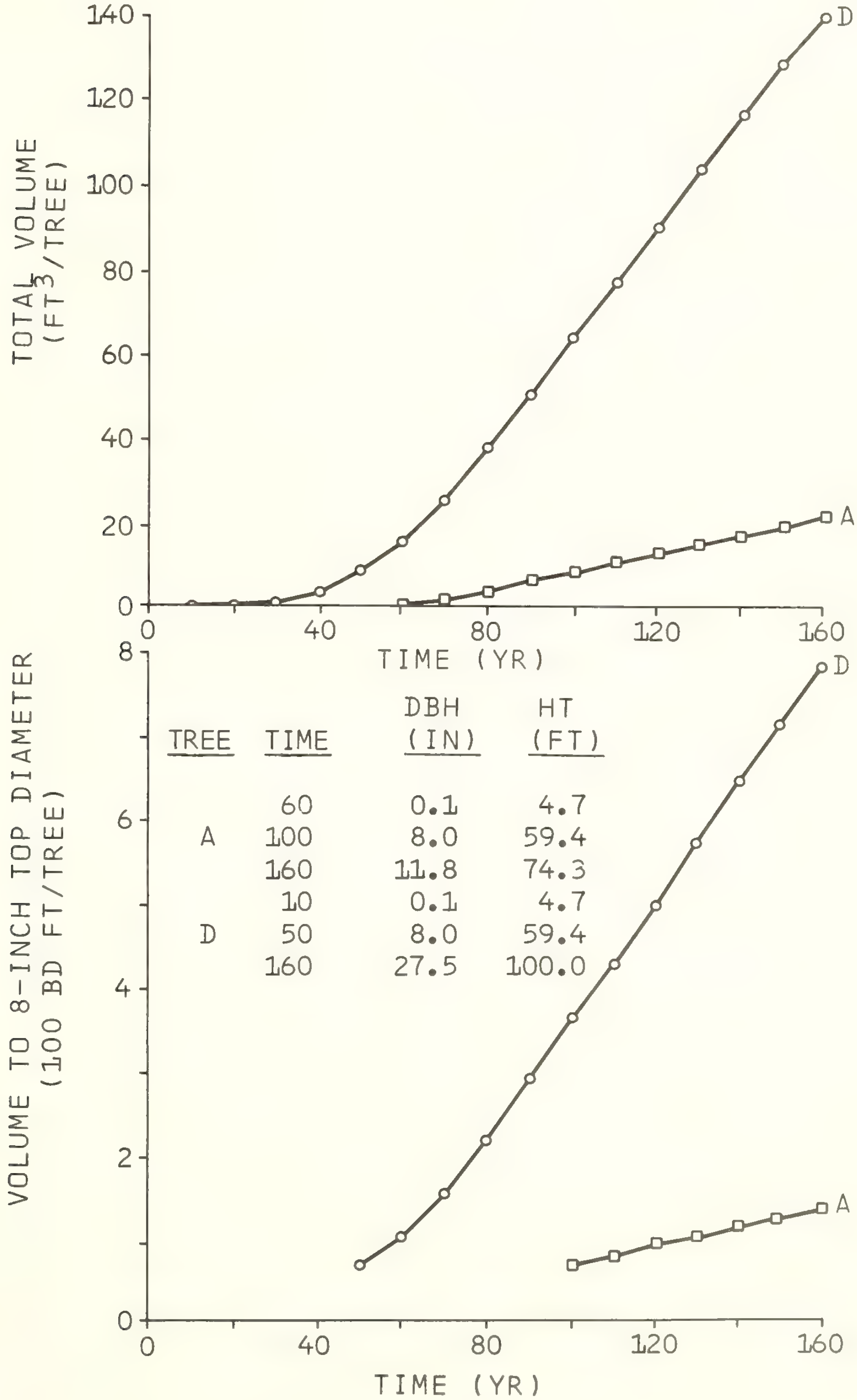


Figure 39.—Scribner bd. ft. and total cubic foot volume predictions for dominant (D) and intermediate (A) Douglas-fir as simulated through time.

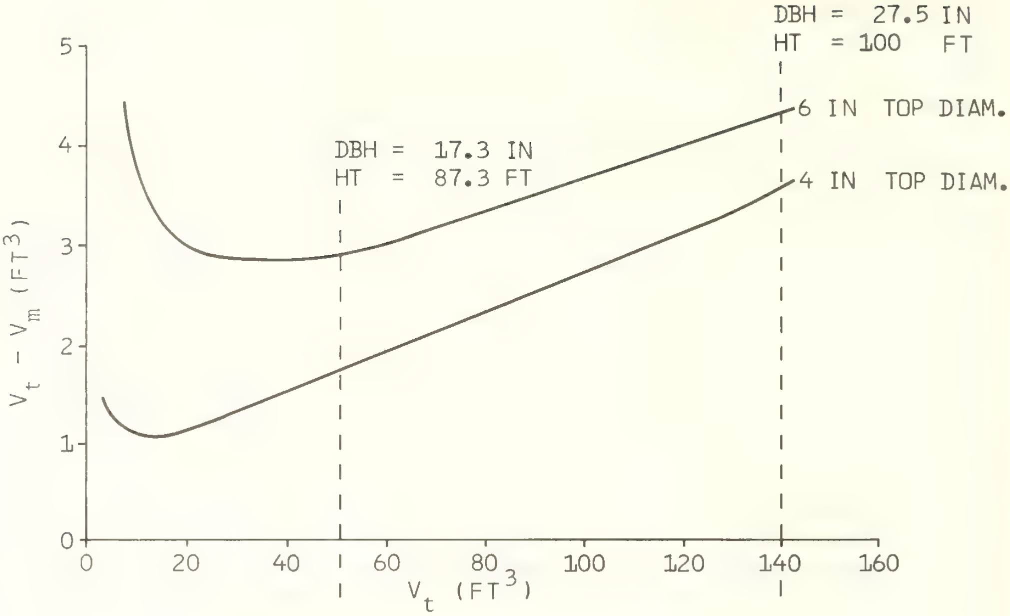


Figure 40.—Difference between predicted total cubic foot volume (V_t) and cubic foot volume to two top diameters (V_m) over time. One-foot stump height assumed; species is Douglas-fir.

USING THE PROGNOSIS MODEL AS A COMPONENT OF A PLANNING SYSTEM

So far, we have described ''using the Prognosis Model'' from the viewpoint of interacting with a computer. We have discussed how to prepare input and how to interpret output, and we have tried to give some insight as to how input is converted to output. All the while, we have adroitly sidestepped consideration of why you might want to use the model.

The Prognosis Model was designed to be a component in a forest management planning system. In this regard there are two levels of application: planning for individual stands and planning for large ownerships that are comprised of many stands. In the first case, we prescribe a specific silvicultural treatment, and we want to evaluate how the treatment influences the development of the stand. In the second case, we establish a broad management policy and we want to evaluate how that policy influences the yield from the ownership over time. The Prognosis Model is adapted to both of these applications.

Resource Allocation and Harvest Scheduling

The Prognosis Model will represent a wide range of stand management activities. The influence of these activities on timber production is explicitly represented and linkages are provided for evaluating pest impacts and estimating interactions with output from other resources. As a result, the Prognosis Model is ideally suited for the preparation of yield tables to be used with algorithms that optimize the allocation of resources.

INVENTORY CONSIDERATIONS

The application of the Prognosis Model to forest planning is enhanced by an inventory system that is based on clusters of sampled stands (Stage and Alley 1972). Future yields are estimated for each sample stand **prior to** aggregation into classes. It is not necessary that all stands within a class produce yields or be scheduled for treatment at the same time. Therefore, errors of aggregation are avoided in the specifications of appropriate stand prescriptions and in the calculation of yields when the prescriptions are invoked. If the conditions

and proposed prescriptions for adjacent stands are considered in the preparation of prescriptions, then the clustering of sample stands will provide the basis for better representation of interactions among stands. This combination of inventory and yield calculation was used in the preparation of a harvest schedule for the Bitterroot National Forest (Stage and others 1980).

Not all existing inventories are designed around examinations of stands. Single plots or plot-clusters widely dispersed over an ownership have been a mainstay of forest inventory design for many years. It is feasible to use this model to compile and project data for a forest inventoried with such designs. In these cases, the concept of "stand" is extended to include aggregates of plots that are as nearly alike with respect to habitat type, slope, aspect, elevation, and tree size classes as is possible. A minor difficulty may arise if the number of tree records in the aggregate exceeds the dimensions of the tree-list arrays in the model. In that case, the classes should be defined more narrowly, or arbitrarily split prior to projection. Re-aggregation after projection is always possible. Moeur and Ek (1981) have shown that errors of aggregation across plots and stands may not be great if no management is simulated.

The aggregation errors may not be serious if all plots in an aggregate receive the same prescription for management at the same times. Unfortunately, a scattered plot design does not permit one to determine whether treatments prescribed for a small plot or plot-cluster will be applicable for an operational tract.

PEST IMPACTS

The use of the Prognosis Model for forest planning is further enhanced by linkage to models that predict the interaction between specific pests and stand and tree development. Currently, there are three Prognosis Model extensions that are designed to simulate pest outbreaks and resultant stand damage:

DFTM—a Douglas-fir tussock moth population dynamics model (Brookes and others 1978);

MPB—a mountain pine beetle population dynamics model (Crookston and others 1978); and,

WSBW—a western spruce budworm population dynamics model (McNamee and others 1980, Colbert and others 1981).

These models are represented by substantial computer programs that must be linked to the Prognosis Model. In a projection, they interact dynamically with the Prognosis Model tree list. Each extension requires special input to describe certain model parameters and management options. This input is controlled with a keyword language that is identical in structure to the system described in this manual. The special input is inserted in the projection run stream, in a contiguous packet of keyword records that begins with the appropriate acronym (DFTM, MPB, or WSBW) and ends with the END record. The options available, and the keywords used to invoke them, are (or will be) described in separate manuals (Monserud and Crookston 1982; Burnell and Crookston[13,14]).

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[13]Burnell, D. G. and N. L. Crookston. 1980. Computing algorithms used in the mountain pine beetle model: an extension to the stand prognosis system. Review draft on file with Leader, Quantitative Analysis of Forest Management Practices and Resources for Planning and Control Research Work Unit, Intermountain Forest and Range Experiment Station, Moscow, Idaho.

[14]At this writing the WSBW model is still under development and preparation of a user's manual has not begun.

MULTIRESOURCE ALLOCATION PROBLEMS

Timber management policy and resulting timber yields have a great deal of influence on the yields of other resources from the forest. Models that predict various resource yields should interact dynamically. An example of this type of application is the Gospel-Hump multipurpose resource development plan that is currently in preparation.[15] This plan is being developed using models that predict water yields, water quality, resident and anadromous fish populations, and elk and moose populations. These models are linked to timber production through two Prognosis Model extensions that predict shrub cover and browse availability (Irwin and Peek 1979) and tree canopy coverage (Moeur 1981). These extensions, SHRUB and COVER, are invoked in a manner analogous to the use of the pest impact extensions described in the previous section. The parameters and options associated with these extensions are documented elsewhere (Moeur and Scharosch[16]).

Stand Prescription

In large-scale planning applications, policies are established to direct stocking control and harvest activities, and scheduling is dependent on stand development over time. The THINAUTO and SPECPREF options represent opportunities for dynamic implementation of policy without user intervention. In contrast, on the level of the individual stand, we are frequently concerned about specific trees and their environment. In this context, we are usually more familiar with stand structure. The Prognosis Model can be used to evaluate trial markings or other thinning options that are tailored to alter the structure of a specific stand.

When the Prognosis Model is used in this mode, its limitations must be carefully considered. Features such as the calibration procedure and the individual tree design are intended to localize the predictions to represent a specific stand. However, many sources of variation are still unaccounted for. Some of these sources, such as differences in tree vigor, incidence of disease, and insect damage will be visible to the knowledgeable silviculturist but not to the model. Projections must be viewed as reference points from which to estimate how the real stand can be expected to develop. If the expected departures are significant and if subsequent economic analyses of the output are required, then keywords that modify the model (see appendix A) can be invoked to bring the output into agreement with the expectations of the silviculturist. Obviously, this procedure must be used with deliberate caution.

REGENERATION SYSTEMS

The evaluation of a stand prescription may require the simulation of a regeneration treatment and the subsequent development of a regenerated stand. A Prognosis Model extension, ESTAB, has been developed to meet this need for the cedar-hemlock ecosystem in the Inland Empire. Currently, the regeneration establishment model is being linked directly to the Prognosis Model. It is also being expanded to represent other habitat types. ESTAB is used in a manner similar to other extensions, and input options are described in a separate manual (Stage and Ferguson 1982).

ECONOMIC EVALUATION OF PRESCRIPTIONS

The economic ramifications of individual stand prescriptions can be evaluated with an independent extension called CHEAPO. Unlike other Prognosis Models extensions, CHEAPO does not interact dynamically with the Prognosis Model. It does, however, use special Prognosis Model output as input. A manual describes CHEAPO options and their implementation (Medema and Hatch 1979).

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[15]Preliminary report on file with Leader, Quantitative Analysis of Forest Management Practices and Resources for Planning and Control Research Work Unit, Intermountain Forest and Range Experiment Station, Moscow, Idaho.

[16]Moeur, M. E., and S. Scharosch. 1981. COVER and BROWSE extensions to the Prognosis Model. Rough draft on file in Moscow, Idaho (see footnote 15).

SUMMARY

In this manual we describe the Prognosis Model in terms of model structure and behavior, options and input requirements, interpretation of output, and planning applications. The document is an accurate and complete representation of the model in its present form. However, as time passes, the Prognosis Model will undoubtedly undergo substantial modification. We will attempt to maintain the user's manual and, to the extent possible, the performance stability of the Model.

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APPENDIX A: REPRESENTING DIFFERENCES BETWEEN THE REAL WORLD AND THE MODEL

Introduction

In our discussion of the Prognosis Model we presented a relatively high level abstraction of tree growth processes and silvicultural practices. To develop this abstraction, the geographic and ecologic scope of the model was carefully restricted and the influence of many potentially descriptive variables was ignored. However, we feel that the model does a reasonably good job of projecting yields for managed and unmanaged stands in the Northern Rocky Mountain area.

We recognize that situations exist where the model may perform poorly. We have added several control variables that should facilitate improvement of performance in these situations. First, we have added a built-in scaling procedure that adjusts the intercept terms in the small tree height increment model and the diameter increment model so that predicted growth matches observed growth for the median trees. Scale factor calculations can be modified or bypassed.

Second, we have represented random effects in the model in various ways (Stage 1973b), and there are options that alter or entirely suppress the application of random effects.

Third, we have supplied options to input multipliers for all the increment functions. Additional options that affect the behavior of the mortality models can be targeted to specific species and to specific cycles.

Finally, we have supplied some options that provide input and output flexibility that may be useful in large-scale applications or when the program malfunctions.

This appendix will discuss the keywords that provide these options. These options are not intended as a vehicle for molding Prognosis output to match preconceived notions of stand development. The range of the Prognosis Model can be effectively extended by judicious use of scaling factors and multipliers. However, changes should be approached with caution, and they should be based on increment and yield data. In most cases where extensive modification is necessary, reestimation of some or all model parameters is in order. If data are available, estimation procedures are fairly routine (Stage 1973b, 1975; Cole and Stage 1972; Hamilton and Edwards 1976).

Calculation of Scale Factors

The increment models that were discussed in the preceding section are based on the best available data. For the most part, the data are representative of growing conditions in the Inland Empire, and the models produce relatively unbiased estimates of growth. However, it is reasonable to expect considerable variation about the expected value of the predictions for any set of values of the predictor variables. Many sites that we perceive to be the same, in terms of the variables used to predict growth, are in fact different, and the differences are reflected in growth rates. The tree is the ultimate integrator of site factors, and tree growth is the ultimate indicator of site capability.

We use available increment data to modify predictions. Most commonly, data are available for periodic *DBH* increment. Periodic height increment, on smaller trees, can be readily measured as well.

The scaling procedure (Stage 1973b), when stripped of statistical condiments, is really quite simple. The affected models are both linear with logarithmically scaled dependent variables. Therefore, the model intercepts are, in effect, growth multipliers. We predict an increment to match each observed increment for a species and sort the differences. The median difference is then added to the model for that species, on the logarithmic scale, as an additional intercept term.

The diameter increment scale factors are attentuated over time. We assume that, on long-term projections, the base model is a more stable estimate of growth potential than is the scale factor. The attenuation is asymptotic to one-half the difference between the initial value of the scale factor and 1. The rate of attenuation is dependent only on time.

The calculation of scale factors can be suppressed by inserting

NOCALIB

in the keyword file. There are no associated parameters. This option is useful when comparing the influence of site characteristics such as elevation, habitat type, slope, aspect, and location on stand development.

One possibility for extending the effective range of the Prognosis Model is to use the scale factors as a means of calibration. If a representative inventory of stands from a new area is available with increment data, the stands can be projected with the Inland Empire version for a single cycle to generate scale factors. If there is a consistent bias in the scale factors for any species, the average value of the scale factors for that species can be entered into the Prognosis Model in subsequent runs, and the model will be adjusted accordingly **prior to** scaling. In effect, the average scale factor becomes a new estimate of the model intercept. The factors for the *DBH* increment model are entered using

READCORD.

The factors for the small tree height increment model are entered using

READCORR.

Although no built-in calibration of the large tree height increment model is available, we have included a facility to preload multipliers for this model as well. These multipliers are entered with

READCORH.

None of these keywords use any of the parameter fields. However, all require two supplemental data records to enter the scale factors. The factors are coded as multipliers in the following order:

Supplemental record number	Columns	Multiplier for species
1	1-10	White pine
	11-20	Western larch
	21-30	Douglas-fir
	31-40	Grand fir
	41-50	Western hemlock
	51-60	Western redcedar
	61-70	Lodgepole pine
	71-80	Engelmann spruce
2	1-10	Subalpine fir
	11-20	Ponderosa pine
	21-30	Mountain hemlock

Decimal points should be explicitly punched. You need only enter the scale factors that differ from 1 as zero or blank values will be interpreted as equal to 1. Scale factors entered with the READCORD, READCORR, and READCORH records are **not** attenuated over time.

Scale factors that are entered in the above manner can be used in subsequent projections in the same run stream without being reentered. This is accomplished by inserting

REUSCORD
REUSCORR
and/or REUSCORH

in the keyword file for the projection in which the scale factors are to be reused. None of the parameter fields are used and no supplemental data records are required.

The calibration procedure described above changes the increment prediction in a proportional manner. It does not influence the relative effects of the predictor variables and there is no change in the shape of the response surface.

Our models are high-level abstractions. The connections between our set of predictor variables and physiological processes that actually control tree growth are, at best, tenuous. Therefore, it is unreasonable to assume that growth responses in locations with substantially different environmental limitations will be the same. It is more likely that the shape of the response surface in these locations, relative to our set of predictor variables, will be different. When this is the case, the models should be refit.

Random Effects

Random effects are incorporated in the Prognosis Model in the manner described by Stage (1973b). This description has been updated to reflect changes in program control variables and included below.

The program assigns all random effects to the distribution of errors associated with the prediction of the logarithm of basal area increment. Basal area increment was selected to reflect the stochastic variation because the effects of differing diameter growth rates extend in highly nonlinear ways through most of the remaining components of the model. This distribution of errors is assumed to be Normal, with a mean of zero. The variance of this Normal distribution is computed as a weighted average of two estimates; the first estimate is derived from the regression analysis that developed the prediction function (table 22), and the second estimate is the standard deviation of the differences between the recorded growth for the sample trees in the population (transformed to the logarithm of basal area increment) and their corresponding regression estimates. The weights assigned to these two estimates are (1) the number of observations by habitat type in the data base for the model

for the prior component of error, and (2) the number of growth-sample trees in the stand for the second component of error (Mehta 1972).

Table 22.—Standard errors ($S_{y \cdot x}$) associated with the basal area increment regressions

Species[1]	$S_{y \cdot x}$
WP	0.5130
L	.5520
DF	.5801
GF	.5612
WH	.5384
C	.5709
LP	.4927
S	.5535
AF	.5806
PP	.5069
MH	.4592

[1]Species codes are defined in table 4.

The random component of change in tree *DBH* is treated in two ways, depending on how many tree records make up the stand being projected. When there are many tree records, the effects of any one random deviation on the growth rate of one tree would be blended with many other trees, and the stand totals should be quite stable estimates. Accordingly, a random deviate from the specified distribution is added to the logarithm of basal area increment.

When the stand is represented by relatively few sample trees, however, a different strategy is used. In order to increase the number of replications of the random effects, each tree record is augmented by two additional records. These new records duplicate all characteristics of the tree except the predicted change in *DBH* and the number of trees per acre represented by the source tree record. The trees-per-acre value of the original tree record is reduced to 60 percent of its current value. The two new records are given 15 and 25 percent of the original value; thus, the three records together still represent the same number of trees per acre.

Each of these three records is associated with one of the three portions of the error distribution characterizing the deviations about prediction (fig. 41). The first record, representing 60 percent of the population (approximately the center of the distribution), is given a prediction corresponding to the average value of the deviations in that portion of the Normal distribution. This "biased" point is indicated by A in figure 41. The second record, representing the upper 25 percent of the error distribution, is given a prediction corresponding to point B; and likewise, the record for the lower 15 percent is given a prediction corresponding to point C. With this method, the weighted average prediction for the three records is equal to the estimate associated with the original record.

Regardless of the method used, there is an implicit assumption that the period-to-period correlation between unexplained errors in growth predictions is zero.

Unless otherwise specified, records will be tripled twice or until additional tripling would exceed the program storage capacity for tree records (currently set to 1350). The maximum number of triples can be increased or decreased by using the **NUMTRIP** record or suppressed entirely with the **NOTRIPLE** record.

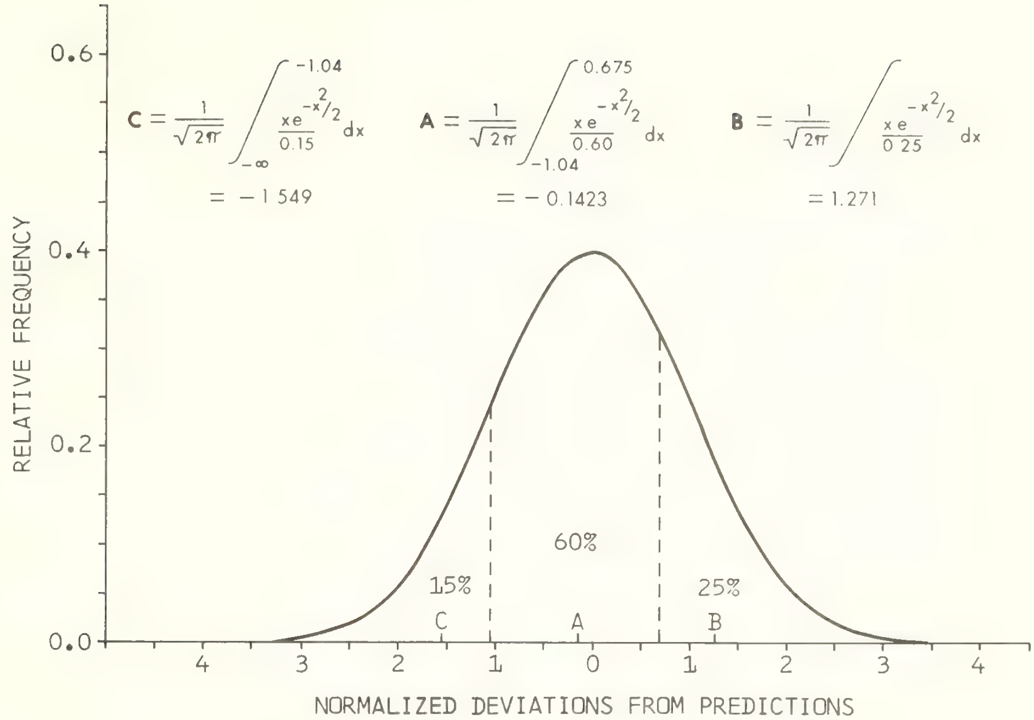

Figure 41.—Location of prediction points (A, B, and C) for three fractions of the Normal distribution.

NUMTRIP	field 1:	The maximum number of cycles in which tree records will be tripled if there is sufficient room in the tree record storage files. A value of 0.0 suppresses the tripling feature; default = 2.

NOTRIPLE uses none of the parameter fields and is analogous to specifying NUMTRIP with 0.0 in field 1.

The region of the Normal distribution from which random increments are drawn is bounded by ± 2 standard deviations. These bounds can be changed with the DGSTDEV record:

DGSTDEV	field 1:	The number of standard deviations that define the bounds of the Normal distribution for random error estimates. Values less than 1.0 will completely suppress the random draw; default = 2.

Random errors are drawn from the Normal distribution by using Batchelor's technique as described in Tocher (1963). This technique requires three pseudorandom uniform numbers to produce each Normal deviate. The uniform pseudorandom numbers are generated with the Marsaglia-Bray composite algorithm (Marsaglia and Bray 1968).

The uniform random number generator is automatically reseeded prior to each Prognosis run so that a given set of tree records and control variables will always produce the same projection output in a specific computing environment. Because the random number generator is dependent in part on the way that a computer stores data and does arithmetic, the output for a given set of input records may vary slightly between computer installations.

It is possible to manually reseed the random number generator and thus produce variation in projection results. There are three seeds involved and they can be replaced with the RANNSEED record:

RANNSEED	field 1:	first seed; default = 1409859205.
	field 2:	second seed; default = 402656419.
	field 3:	third seed; default = −328609067.

Seeds can be replaced individually or as a group. The new seeds should be odd integer values. If they are otherwise, they will automatically be converted to odd integers by truncating fractions and/or adding 1.

Growth Modifiers

The increment and mortality predictions can be arbitrarily modified on a species- and cycle-specific basis. We have included growth modification features primarily for experimental purposes. They may be useful for simulating effects, such as response to fertilizer, that are not now incorporated in the Prognosis Model. They may also be used to test the sensitivity of stand yield predictions to variation in the different aspects of tree growth, regardless of the cause of variation.

The growth multipliers can be entered using one or more of the following records:

BAIMULT - input multipliers for predicted basal area increment.

MORTMULT - input multipliers for predicted mortality rate.

HTGMULT - input multipliers for predicted large tree height increment.

REGHMULT - input multipliers for predicted small tree height increment.

REGDMULT - Input multipliers for predicted small tree diameter increment. These multipliers are not used in Inland Empire version 4.0 because a single model is used to predict *DBH* increment for all trees. However, other regional variants have distinct small-tree *DBH* increment models and multipliers can be input.

With the exception of the keyword, the records for entering growth model multipliers are identical:

BAIMULT MORTMULT HTGMULT REGHMULT REGDMULT	field 1:	Cycle in which growth multiplier is to be applied. Once multipliers take effect, they remain in effect until replaced with a subsequent request. If blank, multipliers take effect at the start of the projection.
	field 2:	Species number (see table 4) to which multiplier is to be applied; default = all species.
	field 3:	The value of the multiplier to be used; default = 1.0.

There is an additional method by which the mortality predictions can be modified. One component of the mortality model is an estimate of maximum basal area attainable on each habitat type. The estimate can be replaced for a projection by using the BAMAX record.

BAMAX field 1: Maximum basal area to be used to control mortality predictions in the projection; default values are listed by habitat type in table 15.

The BAMAX option has proven to be useful when applying the Prognosis Model outside of the Inland Empire. For example, grand fir stands in the Blue Mountains of northeastern Oregon exhibit growth rates that are similar to rates experienced on grand fir habitat types in north Idaho. However, the stands in the Blue Mountains do not appear to attain the stand densities that are possible in the Inland Empire. A maximum basal area can be entered as described above. Mortality predictions will then assure that the maximum is not exceeded, but growth rates will be unaffected.

Special Input Features

Some Prognosis Model applications require the repeated use of a set of keyword records. For example, when the same form and defect correction factors or multipliers are used for a large number of projections, the associated keywords must be entered with each projection. As an alternative, keywords that are used frequently can be stored in an auxiliary machine-readable file. The auxiliary file is then accessed by using an ADDFILE record in each projection:

ADDFILE field 1: Dataset reference number for auxiliary keyword file; must be greater than 16; no default value.

The ADDFILE usually may be inserted anywhere prior to the PROCESS record. You should be mindful, however, of the restrictions relating to TREEFMT, SPCODES, and TREEDATA. When ADDFILE is used, a job control statement must be provided to assign the auxiliary file to the appropriate dataset reference number.

If multiple projections are submitted as a single runstream, the auxiliary keyword file or tree record file may be reentered without providing additional job control statements. This is accomplished by using the REWIND record to reposition the read pointer in the appropriate file.

REWIND field 1: Dataset reference number for input file that is to be reread; default equal to 2.

The REWIND must precede the associated ADDFILE or TREEDATA records in any projection where tree records or the auxiliary keyword file are reread.

Problem Determination

The remaining options relate to the determination of causes of program malfunctions. In the course of development of the Prognosis Model, we have generated a good deal of specious code. Such problems are inherent in programming. To trace these problems, we have added many output statements that report the results of intermediate calculations on a tree-by-tree basis. Most of these special output statements remain in the current version of the code and can be invoked with the DEBUG option in any or all cycles. A word of caution: the DEBUG option generates a great deal of output. For example, the entire output (figs. 6-9) for the hypothetical prescription for stand S248112 requires seven pages. This stand has a relatively small complement of sample tree records. However, when the

DEBUG output is requested for the calibration phase and the first cycle, the entries in the stand composition table for the year 1987 occur at the end of the 18th page of the output.

DEBUG	field 1:	Cycle in which DEBUG output will be printed. If blank, DEBUG output will be printed for the entire projection. When the request includes cycle 1, the DEBUG output will begin immediately and continue through the calibration phase.

The Prognosis Model has evolved over a period of a dozen years and will continue to change. As a result, many versions of the program are in current use, and there will be many future modifications of the code. It is now difficult to reconstruct the origins of any version. As a result, we have initiated a system of code management that will allow us to trace the course of development of future versions. An integral part of the code management system is an output table that reports the date of last revision for each subprogram in the Prognosis Model. This special output is requested with the DATELIST record. There are no associated parameters.

APPENDIX B: SUMMARY OF CODES USED IN THE PROGNOSIS MODEL

Table 23.—Codes for the Forests represented in the Inland Empire version of the Prognosis Model

Forest	Code	Forest	Code
Bitterroot	3	Kaniksu	13
Clearwater	5	Kootenai	14
Coeur d'Alene	6	Lolo	16
Colville	7	Nezperce	17
Flathead	10	St. Joe	18

Table 24.—Codes for habitat types represented in the version of the Prognosis Model[1]

Code	Abbreviation	Habitat type name
130	PIPO/AGSP	*Pinus ponderosa/Agropyron spicatum*
170	PIPO/SYAL	*Pinus ponderosa/Symphoricarpos albus*
250	PSME/VACA	*Pseudotsuga menziesii/Vaccinium caespitosum*
260	PSME/PHMA	*Pseudotsuga menziesii/Physocarpus malvaceus*
280	PSME/VAGL	*Pseudotsuga menziesii/Vaccinium globulare*
290	PSME/LIBO	*Pseudotsuga menziesii/Linnaea borealis*
310	PSME/SYAL	*Pseudotsuga menziesii/Symphoricarpos albus*
320	PSME/CARU	*Pseudotsuga menziesii/Calamagrostis rubescens*
330	PSME/CAGE	*Pseudotsuga menziesii/Carex geyeri*
420	PICEA/CLUN	*Picea/Clintonia uniflorum*
470	PICEA/LIBO	*Picea/Linnaea borealis*
510	ABGR/XETE	*Abies grandis/Xerophyllum tenax*
520	ABGR/CLUN	*Abies grandis/Clintonia uniflorum*
530	THPL/CLUN	*Thuja plicata/Clintonia uniflorum*
540	THPL/ATFI	*Thuja plicata/Athyrium filix-femina*
550	THPL/OPHO	*Thuja plicata/Oplopanax horridum*
570	TSHE/CLUN	*Tsuga heterophylla/Clintonia uniflorum*
610	ABLA/OPHO	*Abies lasiocarpa/Oplopanax horridum*
620	ABLA/CLUN	*Abies lasiocarpa/Clintonia uniflorum*
640	ABLA/VACA	*Abies lasiocarpa/Vaccinium caespitosum*
660	ABLA/LIBO	*Abies lasiocarpa/Linnaea borealis*
670	ABLA/MEFE	*Abies lasiocarpa/Menziesia ferruginea*
680	TSME/MEFE	*Tsuga mertensiana/Menziesia ferruginea*
690	ABLA/XETE	*Abies lasiocarpa/Xerophyllum tenax*
710	TSME/XETE	*Tsuga mertensiana/Xerophyllum tenax*
720	ABLA/VAGL	*Abies lasiocarpa/Vaccinium globulare*
730	ABLA/VASC	*Abies lasiocarpa/Vaccinium scoparium*
830	ABLA/LUHI	*Abies lasiocarpa/Luzula hitchcockii*
850	PIAL-ABLA	*Pinus albicaulis-Abies lasiocarpa*
999	OTHER	

[1]From Pfister and others 1977.

Table 25.—Tree species recognized by the Prognosis Model with coding conventions

Common name	Scientific name	Default input code	Numeric code
Western white pine	*Pinus monticola*	WP	1
Western larch	*Larix occidentalis*	L	2
Douglas-fir	*Pseudotsuga menziesii*	DF	3
Grand fir	*Abies grandis*	GF	4
Western hemlock	*Tsuga heterophylla*	WH	5
Western redcedar	*Thuja plicata*	C	6
Lodgepole pine	*Pinus contorta*	LP	7
Engelmann spruce	*Picea engelmannii*	S	8
Subalpine fir	*Abies lasiocarpa*	AF	9
Ponderosa pine	*Pinus ponderosa*	PP	10
Mountain hemlock	*Tsuga mertensiana*		11

Table 26.—Aspect codes

Aspect	Azimuth (degrees)	Code
North	337.5 - 22.5	1
Northeast	22.6 - 67.5	2
East	67.6 - 112.5	3
Southeast	112.6 - 157.5	4
South	157.6 - 202.5	5
Southwest	202.6 - 247.5	6
West	247.6 - 292.5	7
Northwest	292.5 - 337.5	8
Level	-----	9

Table 27.—Slope codes

Slope angle (%)	Code
≤5	0
6 - 15	1
16 - 25	2
26 - 35	3
36 - 45	4
46 - 55	5
56 - 65	6
66 - 75	7
76 - 85	8
≥86	9

Table 28.—Crown ratio codes

Crown ratio (%)	Code
1 - 10	1
11 - 20	2
21 - 30	3
31 - 40	4
41 - 50	5
51 - 60	6
61 - 70	7
71 - 80	8
≥81	9

Table 29.—Interpreting damage codes (*IDCD*)

Code	Interpretation
73	Tree top is missing
74	Tree top is dead
all others	Ignored

Table 30.—Interpreting tree history codes (ITH)

Code	Interpretation
5	Tree died during mortality observation period; record is used to backdate density for model scaling.
6,7	Tree died prior to mortality observation period; record is ignored.
9	Special record (planar intercept in Region 1 inventory); record is ignored.
1,2,3,4,8	Various categories of live trees; records are projected.

Table 31.—Interpreting tree value codes (*IMC*)

Code	Interpretation
1	Desirable tree
2	Acceptable tree
3	Live cull
8	Non-stockable point
All other codes are interpreted as 3	

APPENDIX C: PROGNOSIS MODEL WARNING MESSAGES

Introduction

Everyone makes mistakes. This section is intended to alert you to the mistakes most frequently made while using the Prognosis Model and to explain the sometimes cryptic messages printed by the system when specific errors are detected. Before we proceed, you should be aware of the following assumptions made by the programers who wrote the error-handling portions of the model:

The tree data file is always correct; the Prognosis Model does not check the tree data file for errors. For example, the Prognosis Model will accept a tree that is 400 feet tall and 2 inches in diameter. However, computational errors will likely result when the model tries to predict this tree's growth.

Supplemental data records (those that follow some keyword records, such as STDIDENT and TREEFMT) are always correctly coded; the Prognosis Model does not check supplemental data records. For example, errors that are due to an incorrectly specified tree data format will probably generate incorrect results and/or error messages that **seem** to be completely unrelated to the tree data format.

The most frequently committed error is misplacing a TREEDATA record before a SPCODES or TREEFMT record. The model prints warning message SPS07 (see the detailed explanation of SPS07) when this sequence is detected. The second most frequently committed error is miscoding the tree data format specification (see TREEFMT record). This error usually causes all of the trees to be grouped in the "other" species category. It may also cause the Prognosis Model to read every other tree record. This error may be detected by checking that the number of records read per species (see the calibration statistics table—fig. 6) is correct for the tree data file.

The Prognosis Model may print several other error messages besides those listed in the next section. Sometimes the message is printed only by an extension, such as the tussock moth model. If you are using one of the extensions, consult the applicable user's manual. At other times, the message indicates a probable system error. If your run contains a message that is not described in this or another appropriate manual, contact your consultant.

Error Message Descriptions

SPS01 ERROR: INVALID KEYWORD WAS SPECIFIED. NUMBER OF RECORDS READ = XXXX

Program Action

If the Prognosis Model cannot interpret a keyword, it is ignored. Supplemental information displaying the keyword specified precedes this error message.

User Response

Find the incorrect keyword, correct it, and rerun the projection. If you are using a version of the model that contains one or more extensions (such as, the tussock moth or mountain pine beetle insect models), it is possible to get this error message when you have specified a valid keyword but have placed it in the incorrect position in the runstream. Consult the applicable user's manual for details.

SPS02 ERROR: NO "STOP" RECORD IN KEYWORD FILE; NUMBER OF RECORDS READ = XXXX

Program Action

The projection is terminated

User Response

If this error occurs after the desired projection is over, no further action is needed. If the message is printed before the projection is over, the probable error is the misplacement of an end-of-file indicator in the runstream. If you use IBM equipment you very likely misplaced any record starting with // or /* . On UNIVAC equipment, a misplaced or miscoded record with an @ sign can cause the same error. Check and correct your runstream and rerun the projection.

SPS03 WARNING: FOREST CODE INDICATES THE GEOGRAPHIC LOCATION IS OUTSIDE THE RANGE OF THE MODEL

Program Action

The growth models use the nearest National Forest to identify geographic location. When the forest code is incorrectly specified or missing from the STDINFO keyword, a National Forest central to the geographical range of the version you are using is assumed.

User Response

Choose the most applicable forest code for your purpose and code it on the STDINFO keyword card. If the default is most applicable, no response is necessary.

SPS04 ERROR: A REQUIRED PARAMETER IS MISSING OR INCORRECT: KEYWORD IGNORED.

Program Action

Supplemental information displaying the keyword record you specified precedes this error message.

User Response

Some of the keyword records require that one or more parameters be specified and that they are within a particular range of values. For example, you may not request that the model run for more than 40 cycles; therefore, coding 50 in field 1 of the NUMCYCLE record will result in an error. Note that incorrectly entering numeric data can easily result in a value being out of range. The value "20" entered in field 1 of the NUMCYCLE record will be read by the program as "200" if the "2" is in column 18 and the "0" is not followed by a decimal point.

SPS05 ERROR: KEYWORD MISSPELLED: FIRST 4 LETTERS MATCH A VALID KEYWORD. NUMBER OF RECORDS READ = XXXX

Program Action

The Prognosis Model assumes that the correct keyword has been found and continues processing. Supplemental information displaying the keyword record you specified precedes this error message.

User Response

If the assumption made by the model is correct, ignore the error. Otherwise, correct the keyword spelling and resubmit the projection.

SPS06 ERROR: COLUMN 1 OF KEYWORD RECORD WAS BLANK. NUMBER OF RECORDS READ = XXXX

Program Action

The record is ignored; supplemental information displaying the record you specified precedes this error message.

User Response

Probable causes of this error are the presence of a stray record in the runstream or the misplacement of a supplemental data record. Correct the mistake and rerun the projection.

SPS07 WARNING: A TREEFMT OR SPCODES RECORD FOLLOWS A TREEDATA RECORD

Program Action

The Prognosis Model continues processing.

User Response

Carefully check your keyword file to assure that TREEFMT, SPCODES, and TREEDATA records are in the proper order. Also assure that the dataset reference number on the TREEDATA record matches the job control statement which, in turn, references the tree record file.

SPS08 ERROR: TOO FEW PROJECTABLE TREE RECORDS. PROJECTABLE RECORDS: XX; TREE RECORDS: XXXX; STAND ID: XXXXXXXX.

Program Action

This error occurs when, after the tree data have been read, a PROCESS record is encountered, and the minimum of two projectable tree records has not been read. If there are fewer than two projectable tree records, the projection of this stand is terminated; however, the next stand in the runstream is projected.

User Response

The most probable cause is attempting to project a very small stand. You may have to delete the stand from your analysis or combine it with an adjacent stand. You may use two TREEDATA records to combine stands.

If the error message indicates that several tree records were read but none were accepted by the Prognosis Model for processing, the most probable causes are incorrectly specifying the tree data format or placing the TREEFMT after the TREEDATA card (see SPSO7).

SPS09 WARNING: PLOT COUNTS DO NOT MATCH DATA ON THE DESIGN RECORD; DESIGN RECORD DATA USED.
PLOT COUNT = XX; NONSTOCKABLE COUNT = XX

Program Action

The Prognosis Model uses the plot count to calculate the trees per acre represented by each tree record. The nonstockable count deducts non-stockable points (such as, rock outcroppings and roads) from the stand area for density calculations. This warning message is printed when either the plot count or nonstockable count differs from the values coded on the DESIGN record.

User Response

Check the trees/acre values as printed in the stand composition and sample tree record tables. If the output is acceptable, no response is necessary.

One probable cause of incorrect plot counting is incorrectly specifying the tree data format thus causing the model to read the plot identifications from the wrong columns. The presence of a TREEDATA card before the TREEFMT card is another probable cause.

SPS10 ERROR: OPTION/ACTIVITY STORAGE AREA IS FULL; REQUEST(S) IGNORED

Program Action

If the storage area which holds activities that are specified to occur at a specified date or cycle (such as, thinning requests) is full when options are specified, the program ignores the keywords and continues. Note that there may be occasions when this error is printed during the projection; in this case, the overfilling was a result of the program attempting to dynamically schedule activities.

User Response

The program can hold several hundred activities and a thousand parameters. Try to limit the number of activities to stay within the memory areas within the program. If you cannot limit your problem ask your programer to increase the activity storage area. (Note to pro-

grammers: Increase the dimensions of the arrays within the OPCOM common area and change the values of *MAXPRM* and *MAXACT* in BLOCK DATA accordingly.)

SPS11 ERROR: REQUESTED EXTENSION IS NOT PART OF THIS PROGRAM.

Program Action

The Prognosis Model ignores the keyword and continues processing. Usually, several SPS01 (invalid keyword) error messages follow this error because most extensions require their own set of keywords.

User Response

You must use a version of the program that contains the extension you require; consult the applicable user's documentation for your computer center and acquire the correct program name. Change your job control statement accordingly and rerun the projection.

SPS13 ERROR: THE MAXIMUM NUMBER OF USABLE TREE RECORDS HAVE BEEN PROCESSED. NUMBER READ = XXXX; SUBPLOT COUNT = XXX

Program Action

The Prognosis Model can handle 1,350 projectable tree records or 200 plots from a given stand. When either of these values are exceeded the projection is terminated.

User Response

If the plot count is exceeded but the tree record count is not, the probable causes are an incorrectly specified tree data format or the occurrence of a TREEDATA card before the TREEFMT card (see error SPS07). Either can cause the plot identification codes to be read from the wrong columns of the tree records. In some cases, the format is accurate—the stand simply has over 200 plots. In these cases, you can change the format specification to read the plot identification from a blank or constant column on the tree records. Then specify the actual count on the DESIGN record and ignore warning message SPS09.

If the tree record count is too high, you may have to split the stand. One technique is to systematically select plots for deletion from the tree record file.

APPENDIX D: SUMMARY OF KEYWORD USE, ASSOCIATED PARAMETERS, AND DEFAULT CONDITIONS

Note: Appendix D contains summaries of keywords that are presented in this manual (page references are given if further clarification is needed). Within each category, keywords are arranged alphabetically.

Rules for Coding Keyword Records

1. All option keywords start in column 1.
2. The numerical values (parameters) needed to implement an option are contained in seven numeric fields that are 10 columns wide. The first parameter field begins in column 11. A decimal point should be punched for all values that are not integers. Integer values should either be right-justified in the numeric field or followed by a decimal point.
3. Blank numeric fields are not treated as zeroes. If a blank field is found, the default value will be used. If zeroes are to be specified, they must be punched. Thus, only the numeric values that are different from the default parameter values need to be specified.
4. All supplemental data records associated with a keyword must be provided if the keyword is used.
5. When two or more conflicting options are specified, the last one specified will be used.

CONTROLLING PROGRAM EXECUTION

Keyword (page reference)	Keyword use and associated parameters	Default parameter or conditions
INVYEAR (8)	Specify the starting date for a projection. **field 1:** Year in which simulation is to begin.	0
NUMCYCLE (8)	Specify the number of cycles in a projection. **field 1:** Number of cycles to be projected; Maximum number of cycles is 40.	1
PROCESS (8)	Marks the end of an input file for a single projection in a runstream and triggers the beginning of the simulation. Must be present or projection will not run.	
STOP (8)	Signal the end of Prognosis Model runstream.	
TIMEINT (8)	Specify the length of any or all projection cycles. **field 1:** Number of a cycle whose length is to be changed. **field 2:** Number of years to be simulated in the cycle(s) referenced in field 1.	Change all cycles 10 years

ENTERING STAND AND TREE CHARACTERISTICS

Keyword (page reference)	Keyword use and associated parameters	Default parameter or conditions
DESIGN (10)	Enter inventory design parameters.	
	field 1: Basal area factor for variable radius plots.	40 ft^2/tree
	field 2: Inverse of fixed plot area.	300 plots/acre
	field 3: DBH separating trees measured on fixed area plot from trees measured on variable radius plot.	5 inches
	field 4: Number of plots used to inventory stand.	Count the plots
	field 5: Number of nonstockable plots in stand inventory.	Count the plots
	field 6: Stand weight for aggregation of projections.	Number of plots
GROWTH (20)	Identify methods used to measure and input mortality and height and diameter increment data.	
	field 1: Method used to measure diameter increment.	0 (past increment)
	field 2: Length of diameter increment measurement period.	10 years
	field 3: Method used to measure height increment.	0 (past increment)
	field 4: Length of height increment measurement period.	5 years
	field 5: Length of mortality observation period.	5 years
MGMTID (11)	Enter an alphanumeric code to identify the silvicultural treatment simulated in a projection. The code does not affect the projection but is printed with each output table and on each line in the Summary table.	Default code is "NONE" (MGMTID record not input); if supplemental record is blank, management identifiers not printed.
	Supplemental record: enter management identifier in first four columns.	
SPCODES (19)	Identify species codes used on the input tree records	
	field 1: Numeric code for the species for which the code is to be changed.	Change for all species
	Supplemental record: Species code or codes, left justified in consecutive 4-column fields. If all codes are replaced, they must be entered in order of numeric code. If only one code is replaced, it is entered in the first 4 columns.	Default values are given in table 4; a blank entry on the supplemental record will be interpreted as a blank.
STDIDENT (11)	Enter stand identification code and descriptive title to label the output.	
	Supplemental record: Stand identification code is entered in columns 1-8; title is entered in columns 9-80.	

(con.)

ENTERING STAND AND TREE CHARACTERISTICS (con.)

Keyword (page reference)	Keyword use and associated parameters	Default parameter or conditions
STDINFO (12)	Enter data that describe the site on which stand is located.	
	field 1: National Forest on which stand is located.	18 (St. Joe)
	field 2: Stand habitat type code.	260 (PSME/PHMA)
	field 3: Stand age.	0 years
	field 4: Stand aspect code.	9 (level)
	field 5: Stand slope code.	0 (< 5%)
	field 6: Stand elevation code.	38 hundred feet
	field 7: Stand site index.	0
TREEDATA (18)	Read tree data from dataset referenced by the unit number recorded in field 1.	
	field 1: Dataset reference number.	2
TREEFMT (19)	Provide a format statement that describes the layout of a tree record.	See table 5
	Two supplemental records: A FORTRAN execution time format statement.	

SPECIFYING MANAGEMENT ACTIVITIES

Keyword (page reference)	Keyword use and associated parameters	Default parameter or Conditions
BFFDLN MCFDLN (24)	Enter species-specific parameters for log-linear form and defect correction equation for board foot volume estimates (BFFDLN) or merchantable cubic foot volume estimates (MCFDLN).	
	field 1: Numeric code for the species for which the equation is to be changed. The default equation supplies a multiplier of 1.0 for each species.	Change all species
	field 2: Intercept term for log-linear equation.	0.0
	field 3: Slope coefficient for log-linear equation.	1.0

(con.)

Keyword (page reference)	Keyword use and associated parameters	Default parameter or conditions
BFFDPOLY MCFDPOLY (23)	Enter species-specific parameters for polynomial form and defect correction equation for board foot volume estimates (BFFDPOLY) or merchantable cubic foot volume estimates (MCFDPOLY).	
	field 1: Numeric code for the species for which the equation is to be changed. The default equation supplies a multiplier of 1.0 for all species.	Change all species
	field 2: Intercept term for polynomial equation.	1.0
	field 3: Coefficient for linear term in polynomial equation.	0.0
	field 4: Coefficient for quadratic term in polynomial equation.	0.0
	field 5: Coefficient for cubic term in polynomial equation.	0.0
	field 6: Coefficient for quartic term in polynomial equation.	0.0
CUTEFF (21)	Change the assumed effectiveness of thinning for all thinning activities.	
	field 1: New value for global cutting efficiency parameter.	0.98
MCFDLN	Parameters same as for BFFDLN.	
MCFDPOLY	Parameters same as for BFFDPOLY.	
MINHARV (22)	Specify minimum acceptable harvest standards for board foot volume, merchantable cubic foot volume, or basal area per acre by cycle.	
	field 1: The cycle in which minimum harvest standards will be applied.	Applied in all cycles
	field 2: The minimum acceptable harvest volume in merchantable cubic feet per acre.	0 ft^3/acre
	field 3: The minimum acceptable harvest volume in board feet per acre.	0 bd.ft./acre
	field 4: The minimum acceptable harvest in square feet of basal area per acre.	0 ft^2/acre
SPECPREF (26)	Change the species component of the removal priority formula.	
	field 1: Date at which change is to be implemented.	Implement at start of projection
	field 2: Numeric code for species whose removal priority is to be changed.	Ignore the request
	field 3: Species preference value.	0

(con.)

Keyword (page reference)	Keyword use and associated parameters	Default parameter or conditions
TCONDMLT (27)	Change the impact of tree value class on the determination of removal priority.	
	field 1: Date at which change is to be implemented.	Implement at start of projection
	field 2: New tree condition class multiplier.	100
THINABA THINATA (27)	Schedule thinning from above to a basal area per acre (THINABA) or a trees per acre (THINATA) target.	
	field 1: Date that thinning is scheduled.	Schedule at start of projection
	field 2: The residual stand density.	Ignore the request
	field 3: Cutting efficiency parameter specific to this thinning request.	0.98
THINAUTO (28)	Schedule automatic stocking control. As nearly as is possible, stand density will be maintained within a range determined by the minimum and maximum percentage of normal stocking entered in fields 2 and 3.	
	field 1: Date that automatic stocking control is scheduled to begin.	Begin at start of projection
	field 2: Percentage of normal stocking that defines the lower limit for stand density.	45%
	field 3: Percentage of normal stocking that defines the upper limit for stand density.	60%
	field 4: Cutting efficiency parameter specific to automatic stocking control request.	0.98
THINBBA THINBTA (27)	Schedule thinning from below to a basal area per acre (THINBBA) or trees per acre (THINBTA) target.	
	field 1: Date that thinning is scheduled.	Scheduled at start of projection
	field 2: The residual stand density.	Ignore the request
	field 3: Cutting efficiency parameter specific to this thinning request.	0.98
THINDBH (24)	Schedule the removal of a segment of the DBH distribution	
	field 1: Date that thinning is scheduled.	Scheduled at start of projection
	field 2: Smallest *DBH* in the segment of the *DBH* distribution to be removed.	0 inches
	field 3: Largest *DBH* in the segment of the *DBH* distribution to be removed.	999 inches
	field 4: Cutting efficiency parameter specific to this thinning request.	0.98

(con.)

SPECIFYING MANAGEMENT ACTIVITIES (con.)

Keyword (page reference)	Keyword use and associated parameters	Default parameter or conditions
THINPRSC (24)	Schedule prescription thinning. Harvest trees that were marked for removal on the input tree records.	
	field 1: Date that prescription thinning is scheduled.	Scheduled at start of projection
	field 2: Cutting efficiency parameter specific to this thinning request.	0.98
VOLUME (22)	Redefine the merchantability limits for the merchantable cubic foot volume equation.	
	field 1: Cycle in which limits defined below will be implemented.	Implement at start of projection
	field 2: Numeric code for the species for which limits are to be changed.	Change for all species
	field 3: Minimum *DBH*.	6 inches for lodgepole pine 7 inches for all other species
	field 4: Minimum top diameter.	4.5 inches
	field 5: Stump height.	1 foot

CONTROLLING PROGRAM OUTPUT

Keyword (page reference)	Keyword use and associated parameters	Default parameter or conditions
COMMENT (48)	Enter a comment that will be reproduced in the Input Summary Table.	
	Supplemental records: Enter your comment using all 80 columns on as many records as desired. Signify the end of your comment by supplying a record with the word "END" entered in the first 3 columns. The 4th column must be blank.	None
ECHOSUM (48)	Request that summary output be copied to a retrievable data storage file.	
	field 1: Dataset reference number for output file.	4
TREELIST (47)	Print a list of all sample tree records.	
	field 1: Cycle in which tree list is to be printed.	Print tree list in all cycles

LINKAGE TO PROGNOSIS MODEL EXTENSIONS

Keyword (page reference)	Keyword use and associated parameters	Default parameter or conditions
CHEAPO (86)	Generate output file required for subsequent execution of the CHEAPO economic analysis program. **field 1:** Dataset reference number for CHEAPO output file.	 11
COVER (86)	Invoke the COVER option in the shrub and cover extension; specify foliage biomass prediction option. **field 1:** Method to be used to compute foliage biomass.	 2
DFTM (85)	Indicates start of special keyword input file for the Douglas-fir tussock moth extension.	
END (85)	Indicates end of special keyword input file for any extension.	
ESTAB (86)	Indicates start of special keyword input file for the regeneration establishment extension.	
MPB (85)	Indicates start of special keyword input file for the mountain pine beetle extension.	
SHRUB (86)	Invoke the BROWSE option of the shrub and cover extension. **field 1:** Number of years since stand was regenerated. **field 2:** Number of years shrub output will be printed. **field 3:** Habitat type code for processing SHRUB option.	 Stand age; see STDINFO 40 years Stand habitat type; see STDINFO
WSBW (85)	Indicates start of special keyword input file for the western spruce budworm extension.	

GROWTH PREDICTION MODIFIERS AND SPECIAL I/O OPTIONS

Keyword (page reference)	Keyword use and associated parameters	Default parameter or conditions
ADDFILE (95)	Specify a dataset reference number for a supplemental keyword record file.	
	field 1: Dataset reference number.	None
BAIMULT HTGMULT MORTMULT REGDMULT REGHMULT (94)	Enter multiplier to change prediction of tree basal area increment (BAIMULT), large tree height increment (HTGMULT), mortality rate (MORTMULT), small tree diameter increment (REGDMULT), or small tree height increment (REGHMULT).	
	field 1: Cycle in which growth multiplier is to be applied.	Apply in all cycles
	field 2: Numeric code for species to which growth multiplier is to be applied.	Apply to all species
	field 3: Growth multiplier.	1.0
BAMAX (95)	Modify the maximum basal area used to control mortality predictions.	
	field 1: Maximum basal area.	See table 17
DATELIST (96)	Instruct program to print date of last revision for Prognosis Model subprograms and common areas.	None
DEBUG (96)	Request printout of the results of most program calculations in any or all cycles.	
	field 1: Cycle in which debug output is to be printed.	Print in all cycles
DGSTDEV (93)	Change the limits of the Normal distribution from which random errors are drawn for increment predictions.	
	field 1: Number of standard deviations that defines the bounds of distribution.	2.0
HTGMULT	Parameters same as for BAIMULT.	
MORTMULT	Parameters same as for BAIMULT.	
NOCALIB (90)	Suppress calculation of scale factors for large tree diameter increment model and small tree height increment model.	Calculate scale factors
NOTRIPLE (93)	Suppress tree record tripling feature.	Tree records tripled twice
NUMTRIP (93)	Change the number of times tree records will be tripled.	
	field 1: Number of triples.	2.0
RANNSEED (94)	Reseed the random number generator.	
	field 1: Replacement for first seed.	1409859205
	field 2: Replacement for second seed.	402656419
	field 3: Replacement for third seed.	−328609067

(con.)

Keyword (page reference)	Keyword use and associated parameters	Default parameter or conditions
READCORD READCORH READCORR (90)	Enter multipliers for the diameter increment model (READCORD), the height increment model (READCORH) or the small tree height increment model (READCORR) that are incorporated prior to model calibration. **Supplemental record 1:** Multipliers for white pine, larch, Douglas-fir, grand fir, western hemlock, western redcedar, lodgepole pine, and Engelmann spruce. **Supplemental record 2:** Multipliers for subalpine fir, ponderosa pine, and mountain hemlock.	Default value for all multipliers is 1.0
REGDMULT	Parameters same as for BAIMULT.	
REGHMULT	Parameters same as for BAIMULT.	
REUSCORD REUSCORH REUSCORR (91)	Use multipliers that were entered with a READCORD, a READCORH, or a READCORR in a previous projection in the same runstream. projection in the same runstream.	
REWIND (95)	Causes the computer to move the read position pointer to the beginning of the dataset referenced by the unit number entered in field 1. This record is useful when multiple projections are made with the same tree record file in a single runstream. **field 1:** Dataset reference number.	2

Wykoff, William R.; Crookston, Nicholas L.; Stage, Albert R. User's guide to the Stand Prognosis Model. Gen. Tech. Rep. INT-133. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1982. 112 p.

The Stand Prognosis Model is a computer program that projects the development of forest stands in the Northern Rocky Mountains. Thinning options allow for simulation of a variety of management strategies. Input consists of a stand inventory, including sample tree records, and a set of option selection instructions. Output includes data normally found in stand, stock, and yield tables and details on selected sample trees. Preparation of input, interpretation of output, and model formulation are described. Guidelines are given for potential uses and limitations.

KEYWORDS: growth and yield, forest management, planning, growth projection, stand models, tree increment, tree mortality

The Intermountain Station, headquarted in Ogden, Utah, is one of eight regional experiment stations charged with providing scientific knowledge to help resource managers meet human needs and protect forest and range ecosystems.

The Intermountain Station includes the States of Montana, Idaho, Utah, Nevada, and western Wyoming. About 231 million acres, or 85 percent, of the land area in the Station territory are classified as forest and rangeland. These lands include grasslands, deserts, shrublands, alpine areas, and well-stocked forests. They supply fiber for forest industries; minerals for energy and industrial development; and water for domestic and industrial consumption. They also provide recreation opportunities for millions of visitors each year.

Field programs and research work units of the Station are maintained in:

Boise, Idaho

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Logan, Utah (in cooperation with Utah State University)

Missoula, Montana (in cooperation with the University of Montana)

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